Report No. 36.

MEDICAL RESEARCH COUNCIL.

INDUSTRIAL FATIGUE RESEARCH BOARD.

On the Design of Machinery in relation to the Operator

By L. A. LEGROS, M.Inst.C.E., M.I.Mech.E., and
H. C. WESTON, M.J.Inst.E.

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PREFACE.

In the attainment of modern productive capacity, associated with the invention and development of power driven machines and the resultant extensive elimination of manual processes, circumstances have made it almost inevitable that attention should have been concentrated chiefly on the improvement of processes in the mechanical sense and comparatively little consideration given to the part in production played by the operator. Yet, in spite of the past expansion in mechanical methods of production, few existing machines are completely automatic, and the large majority still depend for their efficient functioning to a greater or less extent on their operator, whether his role consists merely in feeding the machine, in operating the controls from which production follows, or in adjustment of the working parts determining the size and type of the article produced. It appears, then, that however perfect mechanically a machine may be, there still remains a field for study in the relation of the machine to its operator and in particular in the adaptation of its design to meet his physiological requirements.

It is not, of course, suggested that these requirements have been universally overlooked Special attention has naturally been paid to them in the case of machines (such as the motor car) in which ease of working is an important point in attracting the purchaser, whilst there are other machines, such as many engineering machine tools, in the design of which the interests of the operator have undoubtedly received adequate recognition for the reason that the designer and manufacturer of the machines have had practical experience of their working. Neither is this aspect of design equally important in all machines, for in many instances operation consists merely in short periods of adjustment, alternating with long periods of waiting in which the worker plays no active part.

There still remains, however, a whole class of machines—in actual numbers probably the majority—the working of which calls for the frequent manipulation of a release or control (as in laundry machines, power presses, etc.), or some manual operation performed by the worker at frequent intervals (as in many textile processes). In either case the worker and the machine form a single system, and when it is remembered that the movements involved may be repeated thousands of times daily, the physiological demands made by the operations clearly assume great importance as regards not only production but also the comfort and even the health of the operator.

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In the past, occasional reference has been made to machines defective from this point of view; thus the incidence of Dupuytren's contraction—a disabling contraction of the fingers—amongst lace-winders has been shown to be related to the size and shape of the levers on lace machines and the power required to actuate them,[1] and other examples of ostensibly faulty design in this respect have already been quoted in the Board's published reports.[2] No systematic research on this subject, however, had, so far as the Board were aware, ever been undertaken, and it appeared to them therefore, desirable that a preliminary inquiry should be carried out with the object of exploring the field generally. The results of this inquiry tended to suggest that the design of many machines in common use are in fact capable of improvement in this respect; in some instances the defects were obvious, in others they were merely suspected and could not be established without further observation and experiment.

The Board accordingly decided to initiate an investigation on wider lines under the direction of a special Committee. At the same time they realised that the mechanical aspects of industry under modern conditions are so intimately linked up with the human, that the two cannot be studied wholly apart, and that the elucidation of any general principles governing the relation of normal man to design of machinery could only be hoped for from an investigation on a mechanical as well as on a physiological basis. The subject in short appeared to call for the collaboration of a physiologist with a mechanical engineer of practical experience.

With this object in view, the Board proposed to the Medical Research Council that the advice of the Department of Scientific and Industrial Research on the general scheme of the proposed investigation should be sought and their co-operation on the mechanical side invited. The Board are glad to report that the Department agreed to collaborate in the work by nominating members to join the special committee formed to direct the investigation and by assuming responsibility for a substantial part of the cost. With their approval the mechanical side of the investigation was entrusted to Mr. L. A. Legros, O.B.E., M.I.Mech.E., and Mr. H. C. Weston, M.J.Inst.E. On the physiological side, the Board were fortunate in obtaining the consent of Professor E. P. Cathcart, F.R.S., of Glasgow University, to supervise the necessary research.

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[1] Report of an Inquiry on Dupuytren's Contraction as a Disease of Occupation, by E. L Collis, M.B., and R. Eatock (Home Office, 1912). —*H.M. Stationery Office.*

[2] WYATT, S., AND WESTON, H. C. (1920): Some Observations on Bobbin Winding.—*Report No.* 8, *p.* 9 WESTON, H. C. (1922): A Study of Efficiency in Fine Linen Weaving.—*Report No.* 20, *p.* 6. SMITH, MAY (1922): Some Studies in the Laundry Industry.—*Report No.* 22, *p.* 51.

As initially planned, the investigation was intended to proceed on two lines —

(1) A general survey of repetitive machines with the object of disclosing any existing defects in design.

(2) Physiological research into the energetics of muscle with special reference to the different human movements commonly employed in machine control, with the object of determining the limits within which they can be exercised under favourable conditions.

By pursuing these two lines of inquiry, the Board hoped that a stage would be eventually reached when they would coalesce, and the physiological principles disclosed by the second could be applied to practical needs after being tested by experimentally adapting certain machines to meet the requirements indicated.

It was soon found, however, that the physiological research presented such formidable difficulties in regard to apparatus and technique, that a long time must elapse before any results of practical applicability could emerge from it. The Board, therefore, with the concurrence of their Committee on Machine Design have thought it desirable that the results so far obtained in the first line of investigation should be made available at once for machine manufacturers and others concerned, in the hope that some form of collaboration between them and the Board may follow in respect of further investigation. They have accordingly resolved to publish the present Report, consisting of descriptions of machines in common use, the design of which appears to be capable of improvement in one or more respects.

It is, perhaps, hardly necessary to emphasise its preliminary character, or to point out that it makes no pretence to being a complete survey, but deals only with a few examples of the machines in industrial use. Similarly, the alterations in design, indicated as probable improvements or actually adopted, are based on common sense and close observation rather than on new physiological principles, and must be accepted as suggestions rather than conclusions.

The Board desire to express their indebtedness to the members of the Committee under whose direction the investigation was conducted, and to the various firms who willingly gave facilities for observation.

ON THE DESIGN OF MACHINERY IN RELATION TO THE OPERATOR.

By L. A. LEGROS, M.Inst.C.E., M.I.Mech.E., and
H. C. WESTON, M.J.Inst.E.

CONTENTS.

1. Introduction.

A brief survey of some examples of the evolution of machines will show how obscure and how difficult to recognize have been the causes of the differences between comfort and discomfort, and for how long a period they have produced an amount of fatigue that was large relatively to that due to the performance of useful work.

Probably the simplest example that presents itself, as showing the development of a design to meet the necessary requirements of the user, is that of the bicycle.

At the time of its invention in 1818 in France, the bicycle consisted of a two-wheeled frame with a saddle that supported part of the weight of the driver, who, by propelling himself by the action of his feet on the road, was able to travel at a higher speed than by walking.

The next important advance was the crank-drive, which was first fitted to the "hobby-horse" about 1840 by McMillan, in Scotland; the machine and rider were combined mechanically, but the difficulty of balancing was introduced.

The "bone-shaker," driven on the front wheels, was in use during the sixties. In this machine the front wheel was only some 20 per cent. larger than the back wheel. The mechanical arrangements for the drive were primitive, and the plain bearings of the back wheel and pedals, and more particularly those of the front wheels, which were put out of alinement by the springing of the fork, caused loss of mechanical efficiency. Further, the "bone-shaker" necessitated a cramped position for the body, and the rider suffered from vibration and jolting due to solid metal tyres.

The next step, the "ordinary" bicycle, that came into use in the seventies, comprised two great improvements, namely, the solid india-rubber tyres, which reduced vibration, and the ball-bearings in the hubs and pedals, which reduced the frictional losses. The diameter of the front wheel was about three and a half times the diameter of the back, also more of the weight was now carried on the front wheel, and the position of the driver was improved from the point of view of applying force to the pedals with greater comfort. The mechanical efficiency of the bicycle was, in fact, now very high, but the dynamics of the machine were not appreciated, for although the machines, except when running slowly, were very stable for sideway balance, and the weight distribution was good during propulsion forward on the level or uphill, they were very unstable in the fore and aft direction when running downhill, and still more when the brake was applied, and had a bad element of insecurity on this account.

The next type was the "Facile" bicycle, in which each crank was driven by a short coupling rod from a point near the centre of the length of a rocking lever pivoted on a prolongation of the

front-wheel forks. This construction, although it introduced four extra bearings and reduced the mechanical efficiency, gave much greater fore and aft stability, and consequently safety, than its predecessors, and in 1883 a record of 242½ miles was made on the road in 24 hours by a rider. It was found empirically, however, that the gearing, as measured by ratio of foot movement to distance travelled on the road, was not the most economical, and that a bigger ratio, approximating to, or even exceeding, that of the high ordinary, would give a better result. This led up to the "Kangaroo," which, while geared to the higher ratio, retained some of the defects of the old high ordinary, and had also several bad mechanical features.

The "Kangaroo" was followed by the rear-driven safety invented in 1879, which came into some favour in 1885. This machine was of far better mechanical design than its predecessors, but it had a large increase in the number of working parts, through the addition of the driving shaft with its two bearings, the two chain wheels and the chain. The balance, too, at first was difficult, but it was improved by the upward bend of the front forks. The machine, however, had a new advantage, for the risk from lateral fall was reduced to a negligible amount.

In 1891, the practical pneumatic tyre, although only about a year old, rendered an enormous service to the development of the bicycle. It had already been found possible to reduce the speed of pedalling by increasing the gear ratio of the safety bicycle to 66 inches, and this figure was still further increased when the pneumatic tyre suppressed so large a percentage of vibration from reaching the limbs and the body of the rider.

The bicycle in its history shows a sequence of mechanical improvements from the hobby-horse to the high ordinary bicycle, spread over fifty years, during which its mechanical efficiency was increased to practically the present figure; and a second period in which the human element was recognized as part of the machine and improvements were first made to reduce the risks from falls fore and aft. After these had been eliminated, the mechanical features were altered so as to enable a gear-ratio to be fitted to correspond with the work that could be done. Under the better conditions, the question of safety became fully recognized, and the height of the centre of gravity of the rider was dropped so that the risks from falls sideways were reduced. The remaining important improvements were the pneumatic tyre, which, by diminishing the vibration, eliminated a large proportion of the losses in the human element of the combination of cycle and rider, and gave more power at the circumference of the wheel. This permitted increased speed to be obtained, and also increased mileage, so that by 1900 the 24-hour record had been raised to 600 miles. Finally, the two-speed gear was added, so as to permit of climbing hills which previously had to be walked.

The bicycle, though much of its development was due to results obtained in races, on the track or on the road, was essentially a machine that required to be so designed as to suit any individual, and its ultimate efficiency as a means of enabling its rider to travel from place to place with less effort than by walking, has been attained, first by attention to the physiological requirements of the rider, such as reduction of the vibration communicated to pedal and saddle, and other improvements, enabling a much higher mileage to be obtained for the same exertion by the rider ; and secondly, by meeting the psychological considerations, namely, by improving balance, by diminishing the risk from falls, and by making the machine generally easy and safe to ride. In consequence, the bicycle has been gradually developed from what was practically an acrobat's accessory to a universal means of light transport, and has been made available for women and children. Similarly, in the automobile modifications have been made in the springing by introducing hydraulic damping appliances, fitting auxiliary springs of different periodicity, and so forth, in order to reduce vibrations both of large amplitude caused in running over bumpy roads, and of small amplitude caused by sett-paving, and to mitigate the effect of the wheels leaving the road and being propelled downwards from the frame by the energy stored in the springs, an effect disagreeable to the occupants of the car and destructive to the car itself and to the road.

The evolution of the bicycle may be taken as typical of the evolution that may take place in other machines in which neglect of the user's interests may cause unnecessary fatigue, accompanied by loss of output. In the first stages of the application of mechanical methods to work previously done by human effort, the inventor generally endeavoured to copy, as nearly as possible, the methods and movements previously in use. The early hand-driven typecasting machine, for instance, copied the closing of the mould on the matrix and its presentation to the pump, eliminating the operation of filling by hand, but retaining the other hand motions. The almost complete abandonment of this machine and its products from the equipment of a newspaper office has involved an enormous amount of design and the expenditure of millions of pounds, but the operator of the linotype machine or of the monotype keyboard is no longer compelled to stand at the case, and can produce more work while comfortably seated.

The sewing machine, first made by Thimonier of St. Etienne in 1830, had become practical by 1840, but it owed its general success to the American inventions of the eye-pointed needle and the lockstitch. Hand operating of the sewing machine was at an early stage replaced by a pedal and belt drive, which in turn has now in very many cases been superseded by the power drive, leaving both of the operator's hands free to manipulate the work,

and enabling a greater variety of work to be performed, while relieving the operator of the fatigue due to supplying the motive power.

These examples show how different classes of machines, after years of very limited application, have come rapidly into extensive use by the elimination, or reduction to a negligible quantity, of some previously unsuspected cause of fatigue.

Reference may also be made to other factors in machine design affecting the operator. Many machines, for instance, require considerable movement involving displacement of the body of the operator, and in these cases the standing position is necessary, but the standing position is generally combined with a certain amount of stooping or leaning over. The speed of working is intimately associated with the optimum height of the work. Probably the best recorded example of how far the recognition of this, and of altering from an unsuitable to the optimum height, have led to greater comfort and increased production is given by Henry Ford in his *Life and Work*, pages 81 and 82, as follows :—

> "We had previously assembled the fly-wheel magneto in the usual method With one workman doing a complete job he could turn out from thirty-five to forty pieces in a nine-hour day, or about twenty minutes to an assembly. What he did alone was then spread into twenty-nine operations: that cut down the assembly time to thirteen minutes, ten seconds Then we raised the height of the line eight inches—this was in 1914—and cut the time to seven minutes. In short, the result is this by the aid of scientific study one man is now able to do somewhat more than four did only a comparatively few years ago That line established the efficiency of the method and we now use it everywhere. The assembling of the motor, formerly done by one man, is now divided into eighty-four operations—those men do the work that three times their number formerly did. In a short time we tried out the plan on the chassis.
>
> "About the best we had done in stationary chassis assembling was an average of twelve hours and twenty-eight minutes per chassis. We tried the experiment of drawing the chassis with a rope and windlass down a line two hundred and fifty feet long Six assemblers travelled with the chassis and picked up the parts from piles placed along the line This rough experiment reduced the time to five hours fifty minutes per chassis In the early part of 1914 we elevated the assembly line. We had adopted the policy of 'man-high' work : we had one line twenty-six and three-quarter inches and another twenty-four and one-half inches from the floor —to suit squads of different heights. The waist-high arrangement and a further sub-division of work so that each man had fewer movements cut down the labour time per chassis to one hour thirty-three minutes."

It is remarkable that the recognition of optimum height should in an already well-organized works like those of Ford have resulted in a saving of 46 per cent. in the time of assembling a unit such as the fly-wheel magneto. That this lesson appears to have impressed Ford is clear from the second paragraph, which

shows that it resulted in two different assembly lines being arranged with only $2\frac{1}{4}$ inches difference in height to suit different squads of men. In the case of man-high work, the saving effected over the earlier experiment amounted to 73 per cent. of the time occupied in assembling the chassis. It is to be noted also that Ford does not proceed by increasing the energy expended until up to the limit of the operator's strength, but by keeping well within the limits and turning the operator's work to account more efficiently.

Again, apart from the actual physical fatigue produced by manual exertion or by operating pedals or treadles, there are other cases where machines, as at present designed, do not give the greatest—or even sufficient—clearness of form to the figures and marks on division gear, or are so placed that the parts requiring constant examination by the operator may be difficult to illuminate adequately by ordinary reflected light or by artificial light. The matrix assembly box of the linotype is an example of a case that has been investigated, and one for which methods could apparently be adopted for improving the illumination so as to reduce the eye-strain of the operator.

The comparative neglect of the "human" side of machine design is, however, to some extent explicable. Habit affects machine design in various ways The designer has been accustomed to machines constructed in one particular way, and the workmen similarly become accustomed to such arrangement very rapidly. Little is heard in the way of complaint from the workers, partly because as new entrants they dislike to complain, whilst those used to the machine have ceased to find any inconvenience, and more generally because of the readiness with which the workmen become slaves to habit. It is again of interest to quote from Ford's Life, page 43 :—

> "Habit conduces to a certain inertia, and any disturbance of it affects the mind like trouble It will be recalled that when a study was made of shop methods, so that the workmen might be taught to produce with less useless motion and fatigue, it was most opposed by the workmen themselves. Though they suspected that it was simply a game to get more out of them, what most irked them was that it interfered with the well-worn grooves in which they had been accustomed to move."

Not only is a habit rapidly acquired by the worker, but a habit is also acquired by the designer, who, noticing that the majority of workers are in a standing position at work, designs other machines so that the standing position is the rule.

The adoption of the sitting position wherever possible however, is of advantage from the point of view of avoiding unnecessary fatigue for normal workers as well as of enabling the work to be performed by operatives who are crippled in the legs or feet. The small drilling machine, for instance, had been already improved some years ago by balancing the spindle

so that the operator could work in the sitting position instead of the standing position which had been generally necessary, but the exertion of force at an inconvenient height was still required in holding the heavy head in position and simultaneously tightening it in place with a spanner. At the Machinery Exhibition at Olympia in 1924 there were shown examples of small vertical drilling machines in which, in addition to the balance for the spindle, an independent balance had been added for the head, so that the adjustment of the machine, which is usually necessary for each change of class of work, could be done by the operator, who is usually a young person, without assistance, and also could be carried out by a partially disabled man.

2. **Factors in Machine Design affecting the Operator.**

The investigation, of which this report records the preliminary results, was intended to ascertain avoidable sources of fatigue in the operation of existing machines, with the object of suggesting remedies in the particular designs in which the defects have been found, and, if possible, arriving at some general knowledge that may be useful in future designs. The difficulties of the task are twofold. In the first place, those who use machines habitually have become accustomed to their effect in producing fatigue and are often slow to recognize it as separable from the other circumstances of working. A systematic enquiry, for example, has been made among the Research Associations formed in the principal industries, without eliciting from any of them an indication of machines in which the fatigue of working seemed to be avoidable. Secondly, no data are available for correlating individual circumstances of working with the production of fatigue, nor was there, when this enquiry began, any appliance by which measurements could be made accurately and conveniently of the mechanical energy used in performing some of the most common operations.*

At the present stage, data are not available on which we can safely attempt a classification of the circumstances that may tend to produce avoidable fatigue, and we have therefore confined ourselves to noting those that appear to us the more important, indicating machines in which we have found them occur. The later part of the report describes specific defects found in individual machines, and the measures that have been suggested for remedying them.

* A suitable dynamometer has now been designed, and after trials and improvements constructed. An account of this instrument, and of the work to which it has been applied, will be published later.

The principal circumstances, with examples of the machines in which they occur, noted up to now are :—

Movement (extent, kind, speed, rhythm, and combinations of these), e.g.—

Duplex boring mill	(Engineering).
Mule spinning frame	(Spinning).
Winding frame	(Spinning).
Loom	(Weaving).
Consolidated laster	(Boot and Shoe).
Rough-rounder	(Boot and Shoe).

Posture (height, position of work), e.g.—

Cutting machine	(Tobacco).
Ironing machine	(Shirt and Collar).
Staking machine	(Leather).
Glazing machine	(Leather).
Buffing machine	(Leather).
Bristle punching machine ..	(Brush-making).
Loom	(Weaving).
Decoudun (etc.)	(Laundry).

Effort (includes all machines in which the operative supplies the motive power, and also operates the controls ; also some in which the operation of the control is laborious, such as steering heavy vehicles), e.g.—

Fly-press	(Sheet metal, tile-making).
Pole-lathe, treadle-lathe ..	(Wood-turning and small metal work)
Pumps : reciprocating, rotary, and semi-rotary.	(Various).
Presses, garment	(Laundry).
Guillotines and hand shearing machines.	(Sheet metal).
Steering heavy vehicles ..	(Transport).
Braking heavy vehicles ..	(Transport).

Danger (machines, the working of which is attended by risk of being cut, crushed, or drawn in), e.g.—

French spindle	(Wood-working).
Vertical spindle machine ..	(Wood-working).
Planing machine	(Wood-working).
Staking machine	(Leather).
Shaving machine	(Leather).

Shock (arrested movement or cessation of resistance), e.g.—

Garment press	(Laundry).
Cuff ironer	(Laundry).
Shirt and collar ironer	(Laundry).
Guillotine	(Sheet metal).

Vibration (of the whole machine or of the part held or part operated), e.g.—

Glazing machine	(Leather).
Pneumatic tool	(Mining, quarrying, road-mending).

Noise (produced by the machine or the material on which it operates), e.g.—

Loom	(Weaving).
Glazing machine	(Leather).

Obstruction (of part of machine to the operative or his vision), e.g.—

Hand and power press.. ..	(Light Metal Trades).
Rolling machine	(Tobacco).
Bristle punching press.. ..	(Brush-making).
Looms : Jacquard	(Weaving).
Linotype	(Printing).

Motion (parts of machine moving through a large angle of vision), e.g.—

Glazing machine	(Leather).
Staking machine	(Leather).
Linotype	(Printing).

Adjustment (affected by uncontrollable causes involving uncomfortable posture and avoidable work), e.g.—

Loom	(Weaving).

Many defects in design clearly owe their origin to the designer having failed to recognize that the dimensions of the operative are quite as important as those of the work, and that the combination of machine and operator requires to be considered as a unit no less than the combination of the machine and the work.

Before any substantial advance in this respect can be made, certain basic dimensions, on which at present few data are available, must be accessible to machine designers. Of these, one of the most important, where the work is itself manipulated by hand, is the height of the elbow of the operative in the normal working position, either standing or seated. A typical diagram of this class, Fig. 1, has been prepared from the results of measurements taken on 200 girls, while the girls were actually at their machines or work-tables, each worker standing upright, with the forearm bent at right angles to the upper arm.

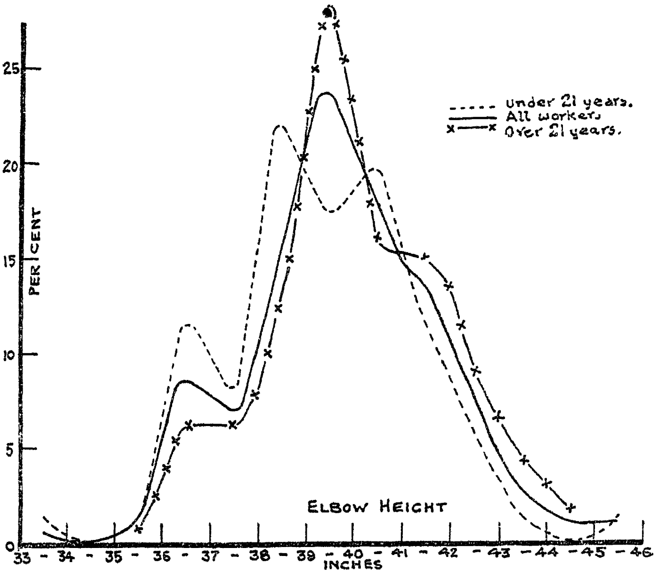

FIG. 1.

The diagram shows that the variation in elbow height of 70 per cent. of the girls was only 1·5 inches, and gives the mean (standing) elbow height at about 39·5 inches above the ground.* Under normal conditions of operating machines, the arm is generally extended in front of the body, and where this is the case 38 inches may be suggested as a comfortable height for the working plane. As a general rule, this height should probably not be reduced or exceeded by more than 1½ inches. In certain cases, however, special considerations may make it inadvisable to fix the height of the working plane within the limits suggested. For example, where the work occupies, or involves, movement over a relatively large area (which must be kept under observation and in any part of which manipulation of the work, or of the tools acting on it, may be necessary), it may be desirable to arrange the working plane at a lower level. On the other hand, with many industrial machines, the adoption of a higher level for the working plane need result in no inconvenience to the operative if standing boards of suitable height are provided. In the case of machines which are operated by means of pedals arranged close to the floor, it would be necessary to raise the height of the pedals by means of some attachment.

* "A series of measurements indicates that 40 inches is an approximate average elbow height, and that a large percentage of the workers will not vary 1½ inches from this measurement" Extract from p. 33 of *Industrial Posture and Seating*, prepared by the Bureau of Women in Industry. State of New York, Department of Labour. Special Bulletin issued under the direction of the Industrial Commission, No. 104, April, 1921.

3. Descriptions of Selected Machines and Suggestions for Improvement.

The large and costly machines used in engineers' shops, often designed by men who have themselves worked on somewhat similar machines of earlier pattern, are for the most part constructed for easy and comfortable operation, with the exception that the seated position, which would be possible and convenient with some machines, is generally ignored. The controls are frequently power operated and centralized, so that the operator need not change his position or move his hand far from one control to another. Such consideration for the operator and for production is not however, so common in machines that have been designed for manual labour that is cheap and unskilled.

The investigations that have been made up to the present relate chiefly to machines peculiar to the laundry and leather manufacturing industries. Descriptions of the machines and suggestions for their improvement will now be given under the headings of the two respective industries.

(*a*) Laundry Machines.

The machines in general use in laundries are those for washing, wringing, starching, drying, ironing, and polishing. The greatest variation in design and method of operation is to be found in ironing machines (some of which also effect the process of drying) and in the machines used for polishing and finishing the work. For this reason, and also because their design has a larger influence on the comfort and efficiency of the operatives, attention has been mainly directed to machines of these types.

Drying and Ironing Machine.

Though the use of large drying and ironing machines of the multiple-roll type is increasing, the single-roll Decoudun is an extremely useful machine and is still extensively used for flat-work.

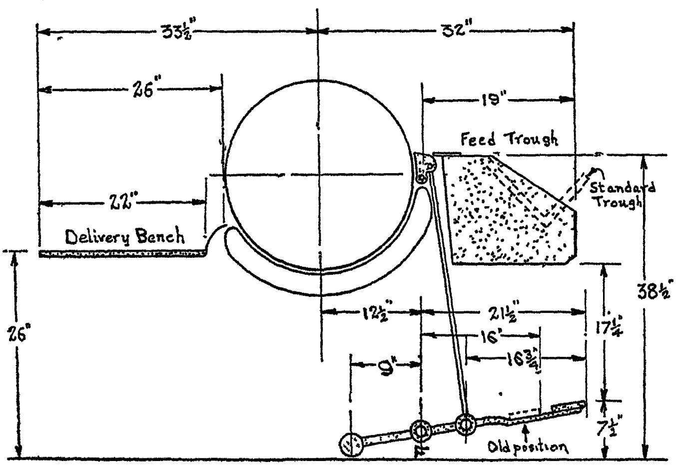

Fig. 2.—Part side elevation of Decoudun Ironing Machines.

This machine is made by several manufacturers, but the general design is substantially the same. Fig. 2 is based on dimensions taken from a machine of this type made by one of the largest manufacturers. The articles to be ironed are contained in a trough from which they are fed to the machine by inserting the leading edge between the roll and a lip which is opened and closed by means of a treadle running the whole length of the machine. They are ironed by pressure against the polished inner surface of the steam chest under the roll, and are then delivered on to a flat bench at the other side of the machine.

The following points in connection with the design suggest themselves :—

(1) Whilst the height of the feed lip as placed by the makers is correct, that of the delivery bench is much too low and necessitates stooping on the part of the operatives. The reason for placing this bench at the height shown is to ensure that the ironed articles shall not be pressed against the cylinder for too long, and thus tend to be carried back to the feed side of the machine. But in practice, even with the existing arrangement, the receiving operative has often to strip the ironed article from the cylinder and it might be possible to incorporate some device which will perform this function automatically, and thus enable the receiving bench to be at a higher level.

(2) Several different types of feed trough are used by different makers of ironing machines and are illustrated in cross-section in Fig. 3. The first of these is largely used and is indicated in

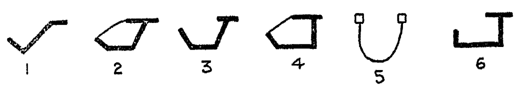

FIG. 3.—Types of Trough used on Ironing Machines.

broken lines (standard trough) on Fig. 2. It is the type supplied with the machine illustrated.

It is difficult to understand that this shape can commend itself to designers upon any ground other than simplicity and low cost. It is the least suitable of all the types shown, as its containing capacity is small, and it is difficult to pick the articles from it quickly and properly without the risk of other articles being pushed out on the floor. Of the types shown in Fig. 3, No 4 appears the most suitable, and in one laundry this has been substituted with advantage for the original pattern.

(3) The arrangement of the feed lip treadle in relation to the trough is important, as an awkward twist of the leg and foot is sometimes necessitated by bad arrangement of those parts. This was found actually to be the case with the machine shown in

Fig. 2; the treadle arms were therefore lengthened by 6 inches and the treadle brought forward to this extent. This alteration has not only removed the necessity for any awkward movement or attitude of the operative, but has also considerably reduced the effort required to depress the treadle by increasing the mechanical advantage given to the worker.

Multiple-Roll Ironing Machine.

These machines are used for flat-work which does not require the highest degree of finish. Since both feed and delivery of the goods are accomplished by means of travelling ribbons or aprons,* the use of a treadle and feed lip is rendered unnecessary.

The height of the feed and delivery on multiple-roll ironers is the principal feature affecting the operatives, and this varies in the machines of different makers, partly owing to the practice adopted by some designers of supporting the rolls in an inclined, instead of a horizontal, frame. Both types appear to give efficient service, but the inclined type is the more common, feeding being done at the highest end. In several of these machines the feed is too high and the delivery end too low, while in others the delivery end only is at fault. Compensation for an unduly high feed level can be obtained by the use of a suitable standing board, but a low delivery end is a defect which cannot be remedied by any such simple means. From the point of view of the comfort and efficiency of the operative, the horizontal type of machine is therefore to be preferred, but if there is any sufficient reason for inclining the bed, the angle of inclination should be reduced to a minimum and care taken to ensure that a convenient height for delivery is secured.

These machines are sometimes fitted with flexible troughs, similar to No. 5 illustrated in Fig. 3 above, but they are usually made rather too deep, and their flexibility does not appear to facilitate extraction of the goods to be ironed.

Shirt and Collar Ironing Machine.

These machines are used for ironing and polishing shirts and collars and they impart a high degree of finish to the work. They are provided with a work-table, controlled by means of a pedal, which alternately shifts a straight and a crossed belt on to the fast pulley, the work being pressed against a heated rotating cylinder as the table moves to and fro. The pedal is usually located on the left side of the machine, as shown in Fig. 4, and the operative generally grips the front of the table and moves the arms to and fro with it, while at the same time depressing and releasing the pedal. Owing to its disposition the

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* The application of a similar device, or of a roller feed, to the Decoudun would be advantageous, and should not add greatly to the size and cost of the machine.

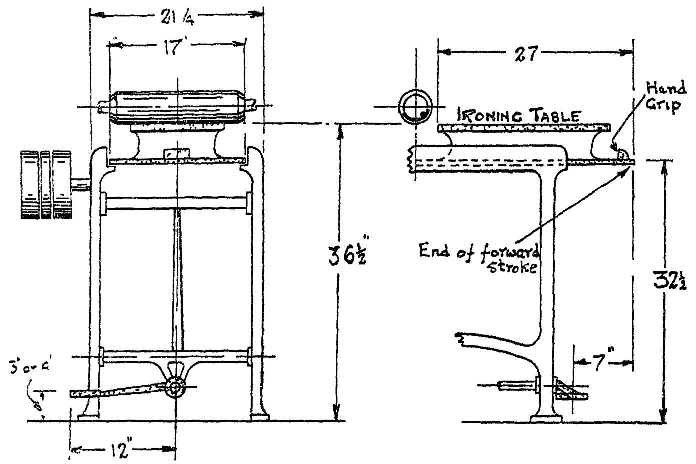

FIG 4 —Part front and side elevation of Shirt Collar Ironing Machine.

pedal can only be operated by the left foot, the weight of the body being continuously supported by the right foot. The left foot is often lifted from the floor when the pedal is in its upper position, though sometimes the heel is rested on the floor and the pedal operated for a time by movement of the foot about the ankle. Whichever method is used, or if each is used alternatively, the operation is tiring.

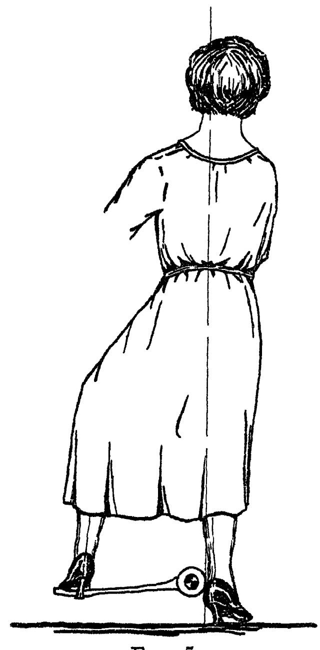

FIG. 5.

There are naturally individual differences of posture and movement used when working with this machine, some operatives working with apparent ease, and others—the majority of those observed—displaying an awkward and unnatural attitude. Fig. 5 shows the kind of attitude assumed in the operation of this

machine owing to its construction. In order to throw the weight of the body on to the right foot, it will be observed that the operative leans to the right, while the left thigh is extended towards the left, so as to bring the left foot on to the pedal This attitude is difficult to maintain, and tends to become a slouch in which the weight of the body is distributed in such manner as to maintain the necessary poise with the least amount of muscular exertion, while the " action " of the worker bears a strong resemblance to the gait of a lame person.

The posture of the operative can be greatly improved if the pedal is centrally placed and can be operated by either foot. A further improvement can be effected by adopting a form of pedal which will enable the operating foot to take its share of the weight of the body. A device designed to meet these requirements, fitted to one of these machines in a laundry for trial under normal working conditions, is shown in Fig. 6. By the adoption of this

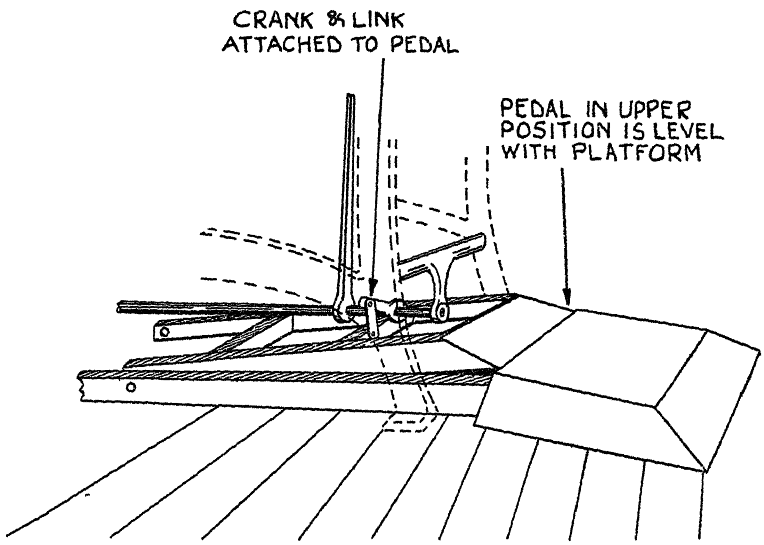

FIG 6.—Improved pedal fitted to Shirt and Collar Ironing Machine.

pedal, the complicated movements previously required of the operator have been converted to a simple to and fro movement, the body being rocked about the heel of one foot and the ball of the other. The pedal is thus depressed quite naturally, the weight of the body is supported on both feet, and, as the pedal is practically as wide as the machine, it can be operated with equal facility by either foot.

The operative usually accompanies the to and fro motion of the ironing table by movement of one or both arms, and, to a certain extent, by movement of the trunk. The motion of the

latter is relatively small, and, even when the table is on its return stroke, the operator often stoops and bends the arms so that effective control of the table can be exercised. The height of the table is important; it is several inches too low in the machine illustrated.

No stops are fitted to these machines to check the motion of the table at either end of its stroke, so that at the end of the forward stroke the table is brought to rest by the hand or body—usually the latter, and by similar means it is pushed on to the driving drum in order to commence the backward stroke. This process is not repeated at every stroke, but is done when commencing and finishing the ironing of a batch of collars, or a shirt, and at any intermediate time should it be necessary to stop the table. If the pedal is not depressed or released before the table reaches the extreme end of its stroke, it may be thrown off the machine with more or less disastrous consequences. This is more likely to happen on the backward than on the forward stroke, but accidents have occurred in which the table has been smashed, or the operative's feet crushed, as even experienced workers sometimes fail to check the motion of the table in time. As it is not difficult to incorporate in the design of these machines suitable means for preventing the table over-running the bed, it is very desirable that this should be done, especially as it is obviously undesirable that the worker should use her body as a buffer for the heavy table.

Garment Press.

The use of these machines is rapidly increasing, as they provide an economical means for carrying out much of the work previously done by hand ironers. Several types are now on the market, all of which operate on the same principle, a cam or toggle arrangement being used to enable great pressure to be put on the work. With one or two exceptions, the suppliers of these machines have no really accurate knowledge of the pressure obtained when the press is locked, and although there seems to be general agreement that the greater the pressure, the better will be the work, the minimum pressure which will suffice to produce good work appears to be an unknown quantity. Most of the machines of this class now in use are operated by hand and foot, but in order to obtain greater pressure than is possible by such means, power-operated presses have quite recently been introduced. Although the latter lighten the work of the operative enormously, they may not come into general use for some time, because they are more expensive than the manual type, and the garment press is so recent an addition to laundry machinery that the useful life of the large number of presses now in use must extend over a number of years. These machines are extensively used where no power is available.

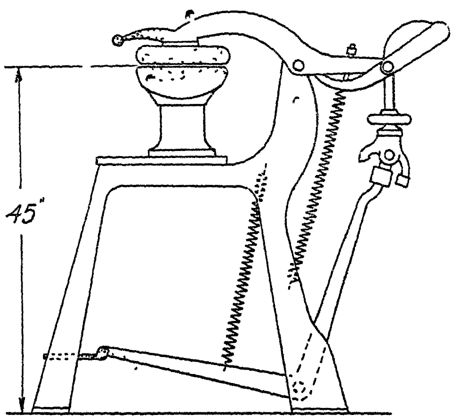

FIG. 7.—Diagram of Garment Press.

FIG. 8.—Garment Presses arranged in tandem. The worker has her right foot on the right hand treadle and with her arms she is bringing down the lid. As she closes the right hand lid the one on her left, now closed, automatically opens. She performs this action on an average about every 15 seconds, with a longer interval when she has finished one article.

In Fig. 7 a diagram is given illustrating the construction of one form of garment press which is in common use, and the accompanying photograph, Fig. 8, shows one of these machines in operation.

The ironing head is attached to one arm of a lever, to the other arm of which is attached a weight, slightly greater than the weight of the ironing head, together with one arm of a toggle. The other toggle arm forms part of a bent lever which carries the locking pedal. Two springs are anchored to the frame of the machine, one of which acts on the pedal lever and the other on the ironing head lever, both springs tending to keep the ironing head at its upper or open position. An extension of the ironing head lever is carried forward to a hand-bar, and in operating the press the worker pulls on this bar to close the press, the operation being assisted by pressure on the pedal A force of about 8 lb. has to be applied to the hand-bar to bring the ironing head approximately to the half-closed position, after which pressure is also applied to the pedal, as the force required to complete the closure then rapidly increases up to a maximum of about 40 lb. Further pressure has then to be applied to the pedal in order to lock the press by forcing the toggle joint on to the dead centre. Owing to the large resistance to be overcome in doing this, it is often not possible to lock the press by gradual pressure, and the operative may therefore perform this operation by throwing the weight of her body on to the pedal When this is done, as soon as the resistance is overcome, there is a momentary period during which the downward movement of the foot or body is rapidly accelerated and then checked with a jolt as the pedal reaches the limit of its travel. This is an objectionable feature, to which attention has previously been drawn,* and it is characteristic of certain other machines, such as the guillotine used for sheet metal-work. To remove this defect, some form of shock-absorbing device is required which will come into play at the moment the press locks. These presses are sometimes arranged in tandem, and may be operated about 150 times an hour, so that it is obviously desirable that they should be made lighter to operate, and any risk of shock to the operative eliminated.

In Fig. 9 is shown a suggested form of shock-absorbing device for machines of this type. By means of an arrangement of this kind the downward travel of the pedal can be continued after the toggle is locked, so that the momentum acquired can be gradually checked by the spring, which comes into action when the trigger is actuated at the moment of locking the toggle.

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* Smith, May. Some Studies in the Laundry Trade: *Reports of the Industrial Fatigue Research Board*, No. 22, 1922.

In two other types of garment press which have been examined, a system of compound levers is used, in place of the simple lever carrying the pedal in the press discussed above, and they are consequently lighter in operation. In another type, the simple lever is used without the springs, and this is also slightly easier to lock, although a pressure of 1,200 lb is obtained between the iron and the buck.

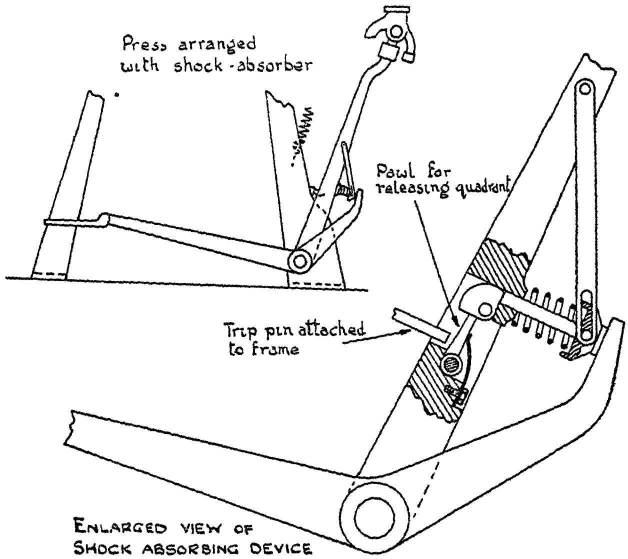

Fig. 9.—Suggested Shock Absorber for Garment Press.

This machine is also designed with a fixed ironing head, the buck being raised by the hand to meet the iron, the operation being very similar to that of raising a wheelbarrow. This design has been adopted because it was thought that the operative could more easily raise the buck, which can be made fairly light, than pull down the iron. This is true, providing the dimensions of the machine, and the angle through which the buck must be moved, are such as to enable the operative to use her arms and legs in the most effective way. In the machine in question, the height of the buck in its open position is satisfactory, but the angle through which it moves should be slightly reduced to ensure maximum comfort in operation.

Cuff Ironing Machine.

In this machine, two vertical push rods, each carrying at the top an inverted V-shaped cuff-holder, are raised into contact with similarly shaped iron by means of pedals. Two pedals are required to operate each cuff-holder, one to raise the holder and the other to release and lower it. The arrangement of the pedals is shown in Fig. 10. Pedal A is depressed to raise one of the cuff-holders, and it remains automatically locked until pedal B is depressed to release it.

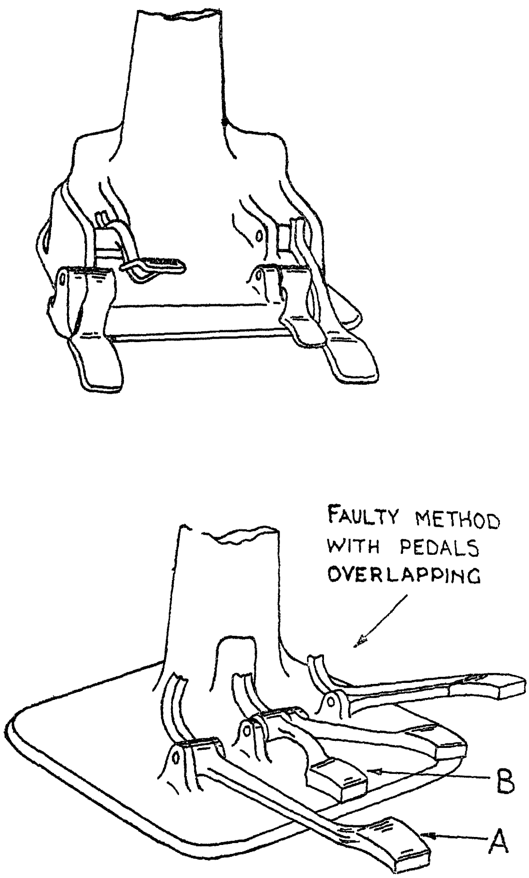

FIG. 10.—Two arrangements of Cuff Ironer pedals.

As the fore part of the foot depresses the pedal B the released cuff-holder drops, causing the pedal A, immediately in front of B, to return sharply to its normal position, thus striking the operator's heel. This is a good example of ill-considered design, in which the operative's interests have been overlooked in order to secure an unnecessarily compact arrangement of the pedals. As a temporary measure, this objectionable feature has been overcome in one laundry by converting the two pedals B into a single pedal by means of a metal connecting strap or bar, so that both cuff-holders are released simultaneously by placing the foot between the two front pedals on to the bar. This method is not suitable as a permanent solution of the difficulty, since the second of each pair of cuffs dealt with will be in contact with the iron for a shorter period than will the first. The real remedy is to arrange all the pedals in line, or better still, to stagger them as shown in the upper part of Fig. 10, sufficient clearance being allowed between each pedal to avoid the possibility of accidental contact of any part of the foot with the pedal adjacent to the one being depressed.

(b) Leather Working Machines.

The design of some of the principal machines used for the manufacture of light leather leaves room for much improvement both as regards the safety and the efficiency of the worker. Four types of machine, all of which are extensively used, will be described. These machines are required for the processes of :—

Staking, in which the leather is stretched in all directions in such a manner as to render it soft and pliant.

Shaving, which reduces all parts of a skin to a fairly uniform thickness.

Fluffing, which gives a soft finish to the flesh side of the skin, and also produces the fine nap characteristic of suède leathers.

Glazing, in which the leather is given a smooth and polished surface.

Staking Machine.

The staking tool employed before the advent of the staking machine, consisted of a half-moon-shaped knife or blade, having a blunt edge, mounted on a wooden stake firmly fixed to the floor. The worker gripped the edges of the skin and, throwing his weight upon it, stretched it tightly across the blade, " working " it to and fro until it acquired the necessary pliancy. The staking machine, part of which is illustrated in Fig. 11, represents an

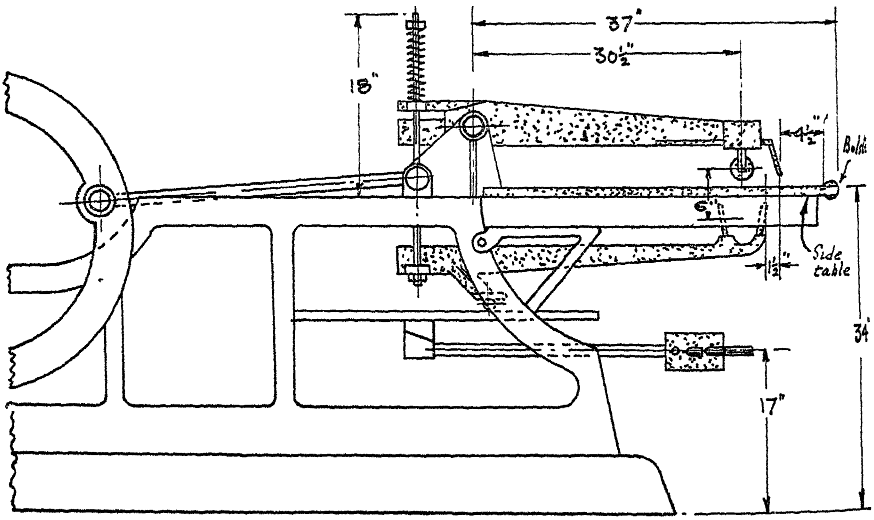

Fig. 11.—Side elevation of Staking Machine.

attempt to imitate, as closely as possible, the treatment applied to the leather by the original manual process, the machine being, in fact, known as the " hand-method " staking machine. Two reciprocating jaws are provided; the lower jaw carries two blades, the front blade being the actual staking tool of somewhat similar form to the old hand tool, and the back blade serving to

prevent the leather from wrinkling. The rubber roller of the upper jaw, which also carries a blunt-edged blade depresses the leather.

The skin to be staked is held between a rubber bolster in front of the machine and the body of the operative, who also grips the edges of the skin and stretches it transversely. The jaws of the machine close at the end of each forward stroke, and, as the rubber roller and blade carried by the upper jaw are arranged to interlock with the blades of the lower jaw, the leather is stretched over the staking tool and then drawn across it as the jaws recede on the backward stroke. The skin is shifted by the operative at each stroke of the machine, to expose a fresh portion to the staking tool, and a device for varying the tension on the leather when the jaws close is fitted beneath the machine and operated by the knees of the worker.

When working with this machine, a considerable amount of stooping is required, and static fatigue of the hand, arm, and abdominal muscles is developed owing to the method of holding the skin. It would be preferable to use the thighs rather than the abdomen for the purpose of pressing the skin against the bolster, especially when women operators are employed. This can be done if the operator stands on a suitable platform, but unfortunately the stoop required is then accentuated In another type of staking machine, the leather is held at the front of the machine by means of an automatic clamp, which is a very desirable feature from the operative's point of view. This machine, however, appears to be unsuitable for treating certain kinds of leather, and it is not extensively used. The machines are often run at a speed of about 100 strokes a minute, so that the shifting of the position of the skin at the end of each stroke requires quick adjustment by hand in rhythm with the jaw movement. During the performance of this, there is some danger of the hands being knocked by the jaws of the machine, or crushed between them, and this is greater in the case of those workers who appear to be fascinated by the reciprocation of the jaws so that their attention is diverted from the position of the hands and leather to the moving parts.*

The knee-controlled tensioning device below the table is not convenient in operation, though it has one advantage over a pedal arrangement in that it leaves the operative free to take a firm stance upon both feet. Recently, a new type of jaw has been introduced, which automatically adjusts the pressure according to the thickness of the leather under treatment, and thus eliminates the knee control. As this device appears to be quite satisfactory in practice, its use should eventually become general.

"The opening and closing motions of the jaws of the machine are quite novelties in leather appliances, and are, in fact, somewhat startling to the beginner. As the operator has to take the entire 'pull' of the machine by the pressure of his body to the leather, it is well to put a fairly strong man to work it, otherwise accidents might occur, or, at least, imperfect skins get hopelessly damaged." From *Leather Manufacture*, by Alexander Watt, 5th edition, 1906, pp. 425 426

There is considerable scope for invention in connexion with the process of staking, and it is suggested that consideration should be given to the possibility of producing the necessary effect upon the leather by entirely new methods, and to evolve a different type of machine easier for the operative to work.

Shaving Machine.

The front of a shaving machine is shown in side elevation in Fig. 12. The cutter is of roller form, running at high speed, and

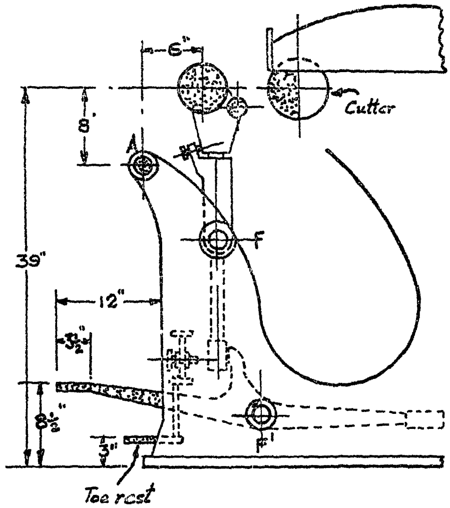

FIG. 12.—Part side elevation of Shaving Machine

has inclined chevron-shaped knives covering the whole surface; the portion nearest the operator moves downwards. The leather is placed over the rollers in front of the cutter, and is then brought into contact with the latter by depressing the pedal which tilts the roller-supporting member about the fulcrum F. The leather may be stretched laterally by the hands and arms of the operator, and the "pull" of the machine is sometimes resisted by pressing the body against the fixed bar A. The weight of the body is supported mainly on one foot, the other foot being kept on the pedal.

It is interesting to note here a feature of design which has not, so far, been encountered in other classes of industrial machinery. This is the toe-rest provided at a lower level than the pedal, which is actually depressed by the heel. While this arrangement possibly allows of more sensitive control, it is very doubtful whether it is as comfortable as the more customary method of supporting the heel and using the ball of the foot to depress the pedal. With the latter method, the movement involved is mainly about the ankle and hip joints, the leg being fairly rigid, and consequently able to support a large portion of the body weight. When, however, the heel is used to depress the pedal, additional movement about the knee-joint is introduced, and the active leg is of little use as a support for the body.

The thickness of a skin varies at the butt, neck, ridge, etc., and the operator has therefore to vary the pressure on the pedal when working on different parts of the leather. If he encounters an unexpected thick patch, as frequently happens, the pull of the machine is temporarily increased, and unless he is sufficiently quick in countering the increased pull by reducing the pressure on the pedal, the skin may be pulled through the machine, carrying the operator's hand on to the cutter.*

This danger is accentuated by the fact that with the type of pedal used the operator tends to lose his balance if he experiences a sudden pull. It is very difficult adequately to guard the cutter without interfering with the action of the machine.† The pedal should also be altered so that it can be operated by the fore part of the foot, and allow the heel to rest on the floor.

This is distinctly a case for a new machine so designed and constructed as to be safe and easy to operate

Fluffing Machine.

The side elevation of a modern fluffing machine is shown in Fig. 13. Above the table, which is slotted in the centre, is a rotating emery wheel, below which is a brush, which also rotates

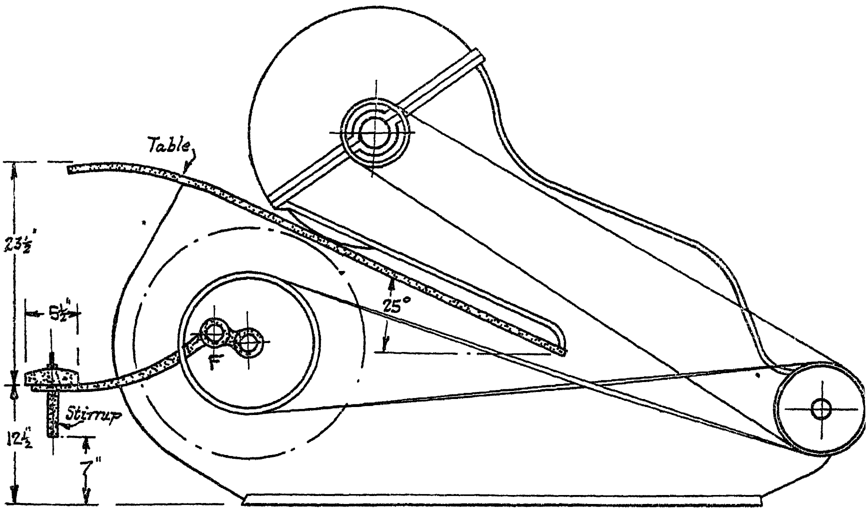

FIG. 13 —Side elevation of Fluffing Machine

* " It is, however, yet capable of improvement, as it is rather dangerous to the operator and somewhat deficient in reducing power on a close firm texture, whilst the flying emery and steel dust is apt to stain ordinary vegetable tanned leather." From *Leather Manufacturing*, By Alexander Watt, 5th edition, 1906, p. 411.

† Since the above was written a machine has been inspected to which a simple and fairly effective guard was fitted The guard operates on the scissors principle, so that as the roller carrying the leather is advanced toward the cutter a smaller roller closes on to the leather. If a sudden pull is experienced the operator's hand strikes the small roller and its further movement on to the cutter is impeded.

and presses the leather against the emery wheel. The brush spindle is carried by a cranked lever, one arm of which is provided with a pedal, with a stirrup attached on the underside. The leather is held in the manner previously described for staking, and is laid on the table so that a portion of it lies between the brush and the fluffing wheel. The foot may be placed either on the pedal or in the stirrup, the lever is then depressed and the brush raised to bring the leather into contact with the emery wheel. The table of this machine is so low that the operator has to stoop considerably, and the pedal is set too high; it is an example of design in which the operative has been neglected.

Glazing Machine.

A certain amount of glazing is still done by hand, the tool used being a piece of thick plate-glass, or a pebble mounted in a "slicker" handle. The process consists in stroking the leather with some force until the whole skin has been given the required degree of polish. The glazing machine shown in Fig. 14 reproduces

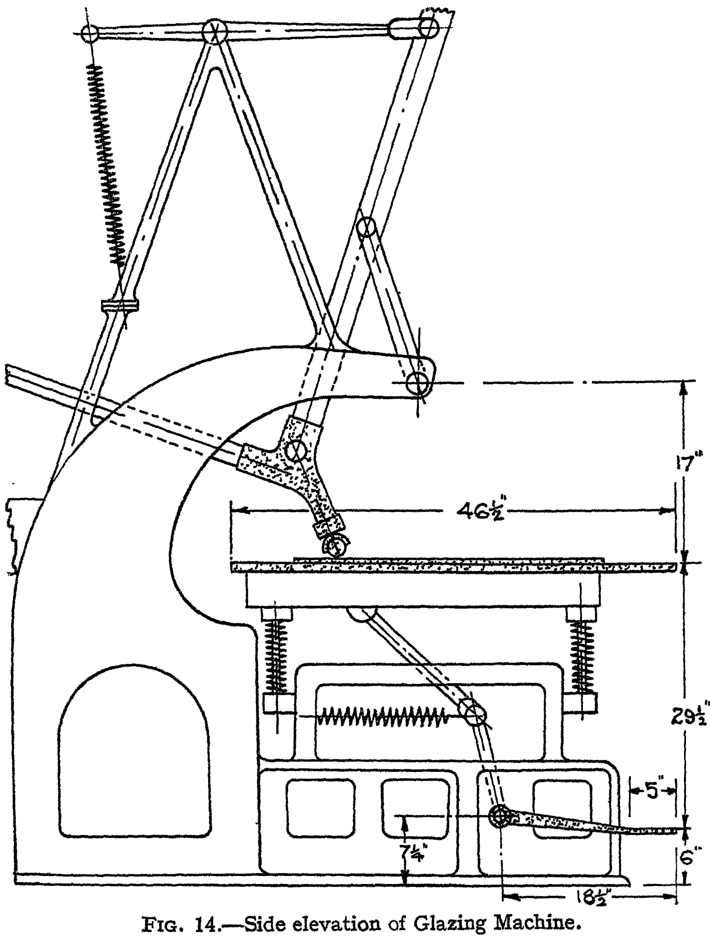

FIG. 14.—Side elevation of Glazing Machine.

this action, but naturally carries it out with greater force and rapidity than is possible by hand. The frame of the machine is constructed of iron, and the reciprocating parts principally of wood, the latter being used because it "gives" sufficiently to allow for inequalities in the leather. The machine illustrated has a horizontal table, but many of the machines in use have inclined tables, similar to the fluffing machine, the two types being used, apparently, for glazing different classes of leather.

In the centre of the table under the glazing tool (which is usually a short piece of glass rod, about 2 inches in diameter) is an adjustable bed, supported at each end in such a manner as to allow some flexibility. The width of the bed is approximately that of the glazing tool, and the bed is inserted in a slotted table, which carries the overlapping portions of the leather.

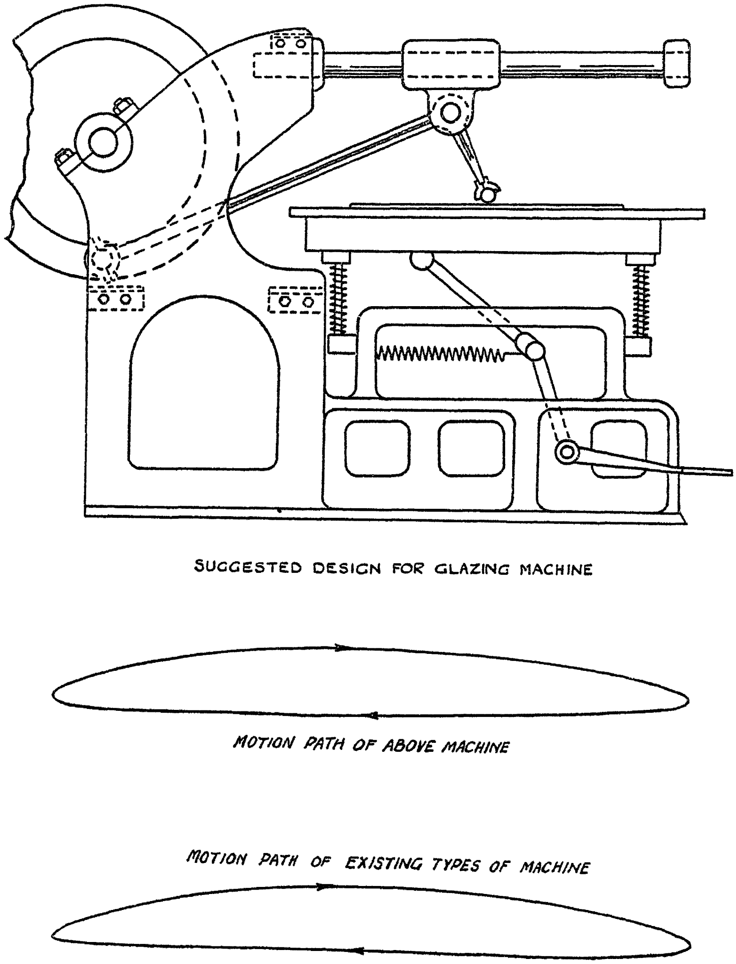

FIG. 15

The leather is placed over this bed, which is about 2 feet long* and about 4 inches wide and can be raised by means of a pedal, to bring the leather into contact with the tool. The machine illustrated is usually worked from the side, but machines having an inclined bed are operated from the front and necessitate much stooping.

The reciprocation of the tool and its associated link-work, which is rapid—about 150 strokes a minute—is an objectionable feature of the machine, since the presence of rapidly moving parts in close proximity to the operator's head has an effect of fascination. This is very trying, and may even lead to accidents, as the moving parts are difficult to guard. This machine produces considerable vibration, which is transmitted to the operator if he keeps his foot on the pedal, as is often done when giving the final polish to the leather, and it is also very noisy. Both defects appear easy to remedy. It should be possible to reduce the vibration by more careful design of the means for raising the bed, and to eliminate much of the noise by securing the mounting of the table which surrounds the bed.

The object of the link-work used on these machines is to cause the tool to move in an approximately straight line during the pressure stroke, but this can also be done if the tool is carried by the free end of a simple cranked connecting rod travelling in a straight guide. A machine designed in this way would be more compact, and the moving parts could be enclosed. The proposed construction is illustrated in Fig. 15, and the diagrams included in this figure show that a motion path can be obtained by this means identical with that of the existing type of machine.

(c) Miscellaneous Machines.

Duplex Vertical Boring Mill.

This is the only example found so far of an engineer's machine tool which shows a lack of centralization of the controls.

It is a large machine provided with two tables, so that two castings, up to about 4 feet in diameter, can be machined simultaneously. The two saddles carrying the tools are arranged at each extremity of a transverse member extending overhead from end to end of the machine, and they can be traversed from the centres of their respective tables outwards (i.e. away from each other) to suit the size of the work to be machined. Each work-table and saddle is separately controlled, the controls being located at each end of the machine. As the length of the machine is about 12 feet, the points at which the tools operate may be separated by about the same distance on large jobs so that the amount of movement required of the operator in inspecting and

* When the pedal is depressed the link attached to the pedal lever causes a plate, carrying a pair of wedges, to move forward against a second pair of wedges mounted on the underside of the bed, thus raising the latter.

controlling this work is considerable. If the two sets of controls were centralized between the two tables, and the traverse of the saddles arranged to be from the centres of the tables towards each other, the cutting points on large jobs would be sufficiently close together to enable the inspection and manipulation of the controls to be effected with much less movement and with a consequent saving of time.

Metal Guillotine (Sheet Metal-working).

The pedal of this machine is depressed against the action of springs provided for the purpose of restoring the blade to its upper position after a cut is made. If the cut is short, the pedal is not depressed to its full extent and the springs are able to check the downward motion of the pedal before it reaches the floor. If the cut is a long one and the material is thick, the pedal is depressed to its full extent, and the last part of the stroke, after the cut is finished, is rapid, the pedal coming to the end of its stroke with a shock as it reaches the floor. This shock is transmitted to the operator.

This defect appears to be well known to users of these machines, who attempt to overcome it either by—

(1) Tightening the springs so that when the cut is finished the force applied to the pedal is insufficient to extend the springs to an extent which will allow the pedal to reach the floor, or

(2) Packing up the machine from the floor so that after a full cut there is room for the idle part of the stroke to be checked by the springs before the pedal reaches the floor.

These methods are bad because—

(*a*) The primary function of the springs is to restore the blade to its upper position, and any spring resistance above that required for this purpose entails extra effort on the part of the operator throughout the whole of the stroke.

(*b*) Packing up the machine, unnecessarily, lengthens the stroke, involving more work for the operator. It also brings the pedal, in its upper position, so high that the operator has to be raised by means of a standing board, otherwise the beginning of the stroke would have to be made with the leg bent in a very ineffective way.

In bad cases, the operator sometimes places a piece of carpet or old doormat on the floor, where the pedal will come into contact with it, so as to reduce the shock. It is desirable that these machines should be fitted with a shock-absorbing device which will come into play on the completion of a full cut. A simple form of air dashpot or spring shock-absorber, similar to those used on automobiles, is all that is required, and could be fitted without difficulty.

Boot and Shoe Machines.

The control of operations on several types of boot and shoe machines involves the use of both hands and feet and one knee, and they therefore demand accurate co-ordination of a number of different movements. In machines of this kind, the arrangement of the controls needs very careful consideration if the simultaneous movements required of the operator are to be executed without undue difficulty. In all of these machines the knee control is an undesirable feature, but it cannot be dispensed with so long as both hands are required for holding and manipulating the work. Recently for the operation of edge-setting, a new machine has been introduced; in this the shoe, instead of being held in the hands, is carried in a travelling jack, the movement of which is governed by the contour of the edge. If this principle can be extended and applied to other boot machines, it will leave the hands free to operate the control at present manipulated by the knee. Two methods of using the knee are employed, the most common of which is for the knee to be inserted in a stirrup, which it moves from side to side; the other method is that of pushing against the action of a spring, which returns the control when pressure is released. If the latter method is used, it is particularly important to see that the more convenient knee is used. In the rough-rounding machine this is not the case. With this machine, the left foot is engaged in depressing a pedal so long as the machine is in operation, and consequently, when the left leg is bent at the knee to operate the knee control, there is a tendency for the pressure on the pedal to be altered. Since the right foot is only intermittently used, the desirability of substituting the right for the left knee seems to be worth consideration.

Bristle Punching Machine (Brush-making).

This machine is used for inserting the bristle in brushes of the cheaper grades, and in celluloid tooth brushes. It requires very close attention from the operator, and, as the punch is arranged horizontally at a low level, constant stooping is necessary. It is also difficult to secure adequate illumination of the work without placing the light source in a position inconvenient to the operative. This machine could probably be designed to operate vertically, when the operator could sit at her work.

Tobacco Machines.

Tobacco-cutting Machines.—Delivery of the tobacco cut by these machines is effected by hand, and the delivery level is much too low, so that the operatives stoop over their work. In future designs there is no reason why this defect should not be remedied.

Tobacco-rolling Machines.—In these machines a bundle of leaves is made into a thick roll by the action of a roller-blind arrangement, similar in principle to that embodied in a familiar form of pocket cigarette-rolling device. Both feed and delivery are hand operations. The feed appears to be easy and convenient, but the roll, when made, is completely out of sight of the operative,

who reaches to the back of the machine to feel for it. Operation of this machine appears to be extremely slow, and re-arrangement of the parts, so as to bring the delivery within sight of the operative, would facilitate his work.

Textile Machines.

Looms.—Although the nature of the work performed by the loom is such that it is probably impossible to construct these machines so as to avoid awkward movements of the operative, there are several features of design capable of improvement. The loom is necessarily a noisy machine owing to the action of the picking mechanism, but the noise might be reduced by improved design of the tappets which operate the healds. The method of suspending the healds is also unsatisfactory, as the cords used are affected by atmospheric changes. The formation of the "shed" may in consequence be inexact, and cause an increase in the number of warp breakages.

Winding Frames.—A full description of the design of winding frames as it affects the operative has been given in a previous report of the Industrial Fatigue Research Board,* but a drawing is reproduced here, Fig. 16, illustrating the variation which may be found in the important dimensions of these machines.

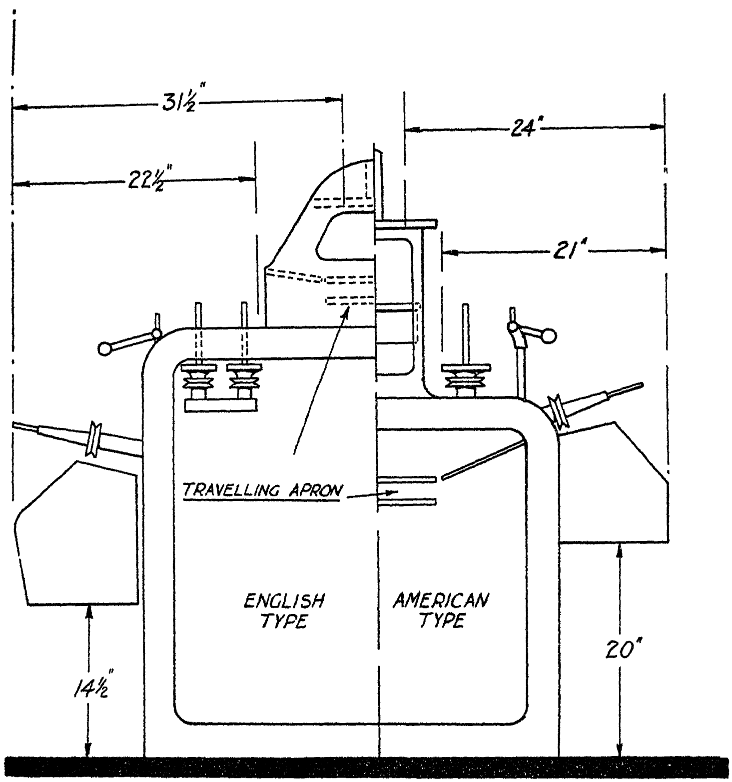

FIG. 16.—Diagram comparing the important dimensions of two types of Cotton Winding Frame

A quite unnecessary amount of stooping and reaching has to be done by a winder, owing to the depth of many winding frames and to the height at which the ring-yarn boxes are placed. The American type of frame is much better than the English type in these respects, and of the latter, some of the latest designs show a tendency to place the ring-yarn boxes even lower than in the earlier designs. There is no difficulty in designing a winding frame which would be well adapted to the average operative, and the points to which attention has been drawn should receive attention in future designs.

4. Summary.

An illustration of the development of machines with respect to their saving of fatigue is afforded by the bicycle, which has been successively modified, first mechanically so as to obtain high efficiency, then psychologically so as to reduce the risk of falling and difficulty of balance, and finally physiologically so as to reduce vibration and to enable the force exerted by the rider to be more efficiently applied. The bicycle as an example is unique, because it has had the advantage of being tested in races and its effect as a means of producing fatigue has consequently been subjected to more severe trial than occurs in the case of machines that are used for industrial purposes.

The evolution of other machines has sometimes been impeded from the outset through too slavish copying of manual movements, with the result that design has proceeded to a certain point, and the machine has then required complete remodelling to work in accordance with sound mechanical principles. An example of such is found in typecasting machinery.

Actual investigation of machines has been carried out, and improvements have been designed for such cases as could be dealt with without involving great expenditure on modification of the machine

Laundry Machines.

In the first instance, for use in connexion with investigations on laundry machines a diagram has been prepared of the elbow height of 200 girls, to serve as a guide for the optimum height at which the work should be performed.

Several types of laundry machines have been examined. In drying and ironing machines, the form of the trough containing the articles to be ironed has been investigated, and improvements suggested, as also for the height of the delivery of the machine.

Improvements have also been suggested to the Decoudun flat ironer and similar machines for the feed and delivery of the goods.

Shirt and collar ironing machines, used for ironing and polishing shirts and collars, have a pedal movement that is generally inconvenient, requiring the weight of the body to be largely supported on one foot. An improvement on this machine has been suggested, and applied in practice, as shown in Figs. 4 and 6 of the report. By the improved arrangement, the pedal can be operated by either foot, and the operating foot can take a share of the weight of the body.

Garment presses are of much more recent origin, and are operated by a combination of hand and foot movements. The pedal movement in overcoming the toggle is performed in such manner that the foot or body of the operator is rapidly accelerated towards the end of the travel, and then checked suddenly; a form of shock-absorbing device has been suggested so as to save the operator from this shock.

The cuff ironing machine is another example of bad pedal arrangement. An improved arrangement with staggered positions for the pedals would avoid the risk of contact of the foot with a pedal adjacent to the one being operated.

Leather Working Machines.

Several of the principal machines used for the manufacture of light leather leave room for improvement. The staking machine is a case of the imitation by machine of the original manual processes for treating leather.

The shaving machine is a machine of the type in which the operative stands on one foot and controls the machine with the heel of the other foot. This unusual arrangement is more peculiar because of the considerable element of danger involved in working the machine.

The fluffing machine is used for giving a soft finish to the flesh side of the skin, and producing the fine nap characteristic of suède leathers. Examples of this type of machine that were examined showed that optimum height has been disregarded in the design.

Glazing machines for smoothing and polishing the leather introduce a different element of fatigue, due to the reciprocation of the tool and its associated link-work; the presence of rapidly moving parts in close proximity to the operator's head having an effect of fascination. An improvement has been suggested in which a different mechanical motion is substituted for that at present in use, and which permits of the moving parts of the machine being enclosed.

Miscellaneous Machines.

Duplex Vertical Boring Mill.—This is a large machine, capable of taking two castings up to 4 feet in diameter and machining them simultaneously. In this instance, the controls are located

respectively at the outer sides of the jobs ; whereas, if located at an intermediate point, the operator could control the work without the necessity of moving from his position between the two tables.

Metal Guillotine.—In shearing light metal, the pedal of the machine travels through a variable length while cutting, and as the cut terminates and resistance is reduced, the downward motion of the pedal becomes accelerated, so that, in general, the operator receives a shock through the stopping of the pedal on the floor or a block. This is a case in which a simple form of dashpot, or shock-absorber, would suffice to eliminate the defect.

Boot and Shoe Machines.—These machines require so many simultaneous and co-ordinated movements of the operator that in some cases the use of both hands, one foot, and a knee is required. From the application of the movements, these machines may well be regarded as being in a transitory stage, and likely eventually to undergo considerable modification.

In the case of the rough-rounding machine, one leg is bent at the knee for operating the knee control, and when this is done, there is a tendency for pressure on the pedal to be reduced. A change of the foot control to the other foot might be tried.

Other Machines.—The bristle punching machine used in brush-making is an example of inadequate illumination and wrong height, causing stooping of the operator.

In the tobacco-cutting machine the delivery level is too low, also causing the operatives to stoop over their work.

In the tobacco-rolling machine, the product is out of sight of the operative, who has to reach over the machine to obtain it.

Textile Machinery.

Amongst textile machinery, *the loom* is very noisy, and some means of reducing the noise would probably be appreciated by all the workers. There is also a difficulty arising out of the method of suspending the healds owing to the length of the cords being affected by atmospheric changes.

Winding Frames.—These have already been noticed in a previous report to the Board. They involve unnecessary stooping and reaching.

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MEDICAL RESEARCH COUNCIL.

INDUSTRIAL
FATIGUE RESEARCH BOARD.

REPORT No. 37.

FAN VENTILATION IN A HUMID WEAVING SHED.

An Experiment made for the Departmental Committee on Humidity in Cotton Weaving.

By S. WYATT, M.Sc.,
assisted by J. A. FRASER, M.A., B.Ed.,
and F. G. L. STOCK.

LONDON:
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PREFACE.

The Board in their Preface to an earlier report* have given a short account of the different official inquiries that have been instituted since 1883 into the effects of artificial humidity on the health and comfort of the operatives in cotton weaving sheds, and of the successive codes of regulations limiting the permissible temperature and humidity in this class of factory which have been based on recommendations arising from these inquiries.

Since this was written, the Home Secretary, in view of the continued objection to the practice of humidification on the part of the operatives, appointed in November, 1924, a new Departmental Committee with the following terms of reference :—

> "To consider and report whether any, and if so, what modifications of the existing statutory regulations governing the use of artificial humidity in cotton cloth factories are desirable and practicable."

At an early stage, the attention of this Committee was directed to the reports† of the Board describing the results of two investigations carried out in the cotton weaving industry, and in particular to the three main conclusions which so far as atmospheric conditions are concerned, arise from them.

First, it appears (so far as can be assumed from a study of sample factories) that in certain respects the physical conditions of the workers' environment in humid cotton weaving sheds do not reach the standard which ought to exist and which is, in fact, attained in other, though not in all, industries. Secondly, above certain limits of temperature and humidity the efficiency of the weaver is impaired by the adverse physiological effects of his environment. Thirdly, there is evidence that in conformity with modern views on the physiology of ventilation, these unfavourable effects could be ameliorated by increasing the air movement in the vicinity of the weaver.

The last of these conclusions was based on an experiment involving the use of a special device attached to the looms, but it was recognised that this device was open to some objection on the grounds that it tended to hamper the free movement of the weaver, whilst other appliances suggested could not be widely adopted for structural reasons The Board accordingly, at the time when the Report concerned was published, invited the attention of the industry to the desirability of devoting special study to the subject, with the object of devising some method of improving the conditions physiologically without interfering with the process of manufacture.

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* Wyatt, S. (1923): Atmospheric Conditions in Cotton Weaving. Report No. 21.

At the time of the appointment of the Departmental Committee no further progress had been made. Accordingly, on their recommendation, the Home Office applied to the Medical Research Council requesting that the Board should be authorised to carry out in collaboration with the Committee a further investigation with the object of determining more precisely the effect on comfort and efficiency of increased air movement, brought about by the use of specially installed fans. With the approval of the Medical Research Council, the Board gladly acquiesced in this proposal, and invited Mr. S. Wyatt, M.Sc., to conduct the experiment of which the results are described in this Report.

The present investigation completely confirms the earlier work on the relation of air movement to comfort and efficiency, and in the opinion of the Board definitely suggests one method by which the unfavourable effects of high temperatures and humidities can be to some extent alleviated.

The Board think it desirable to point out that whilst the actual method used for increasing the air movement in the present experiment gave satisfactory results, it was selected primarily on the grounds that it appeared to be specially suitable for the purpose of the investigation, which was to explore the effects of air movement irrespectively of practical considerations. But there appears to be no reason why other methods, able to achieve the same results, should not be devised, and they hope therefore that in view of the still more definite evidence now available, ventilating engineers and others concerned in the industry will bring their technical knowledge to bear on the subject, with a view to finding some easily controlled means of regulating air movement in a weaving shed which shall not be prohibitive in respect of price and which shall in other respects be suitable for use under practical conditions.

March, 1926.

AN EXPERIMENT WITH FANS IN A HUMID WEAVING SHED.

By S. WYATT, M.Sc.,

assisted by J. A. FRASER, B.A., and F. G. L. STOCK.

CONTENTS

1. Introduction.

The experiments about to be described were carried out for the purpose of determining whether the disagreeable effects of high temperatures and humidities which often prevail in humid weaving sheds during the summer months could be ameliorated by the use of increased air movement produced by fans.

The cooling power of the air in a shed, and consequently the bodily comfort of the operatives, depends upon (*a*) the temperature of the air, (*b*) the amount of water vapour it contains, and (*c*) its rate of movement. A high atmospheric temperature reduces the radiation and convection of heat from the body; a humid atmosphere retards the rate of evaporation of surface moisture on the body, while a stagnant atmosphere impairs both the processes of convection and evaporation. A hot, humid, and stagnant atmosphere is accordingly conducive to the accumulation of heat within the body, with its attendant unfavourable physiological and psychological effects. In many weaving sheds the introduction of artificial humidity in the form of steam is considered necessary for manufacturing purposes. As a result, the atmosphere in such sheds during the summer months is often uncomfortably hot and moist, and must remain so under existing conditions. Any attempt to improve the atmospheric conditions must necessarily involve a modification of one or more of the three factors mentioned above. Since the first two (temperature and humidity) are supposed to be necessary for manufacturing efficiency, the third (rate of air movement) must be considered in this connection.

It is well known that moving air in the vicinity of the body promotes the loss of body heat by (*a*) removing the heated air in contact with the body and entangled in the clothing, (*b*) accelerating the evaporation of superficial moisture. In the former case the heat is conducted more rapidly from the body to the surrounding air, while in the latter heat is taken from the body in converting superficial moisture into water vapour. Because of these considerations, it was thought that the disagreeable effects of a hot, moist atmosphere might be mitigated by increasing the rate of air movement, and for this purpose a number of fans were installed.

The rate of air movement and the cooling effect produced by the fans can be conveniently determined by means of the kata thermometer,[1] and this instrument was used in the present investigation.

---

[1] The kata thermometer is an instrument invented by Professor Leonard Hill. Further particulars regarding its nature and use are given in (*a*) "The Science of Ventilation and Open Air Treatment," Part I (Medical Research Council), and (*b*) Report No. 21 of the Industrial Fatigue Research Board.

Before the investigation was begun, the nature and purpose of the experiments were fully explained to the operatives in the presence of the manager and the local Trade Union Secretary.[1]

2. Procedure Adopted.

For the purpose of these experiments, electrically driven fans were installed in a small humid shed having the following dimensions and equipment :—

No of Looms	*No of Operatives.*	*Length*	*Width*	*Height.*	*Cubical Contents.*	*Style of Weave.*	*Humidification.*	*Ventilation.*
98	26	132′ 6″	33′ 2″	20′ 9″	91,188 cu. ft.	Twills, Satins, Umbrella Cloths, Fancy Casements, up to 14 shaft dobbies.	Vortex and Steam Jets.	Plenum Fans.

The fans were of the gyrating type, and the body of the motor moved through a sweep of 105° horizontally and 45° vertically along an elliptical path. The range of movement of each fan is shown diagramatically in Fig. 1.[2]

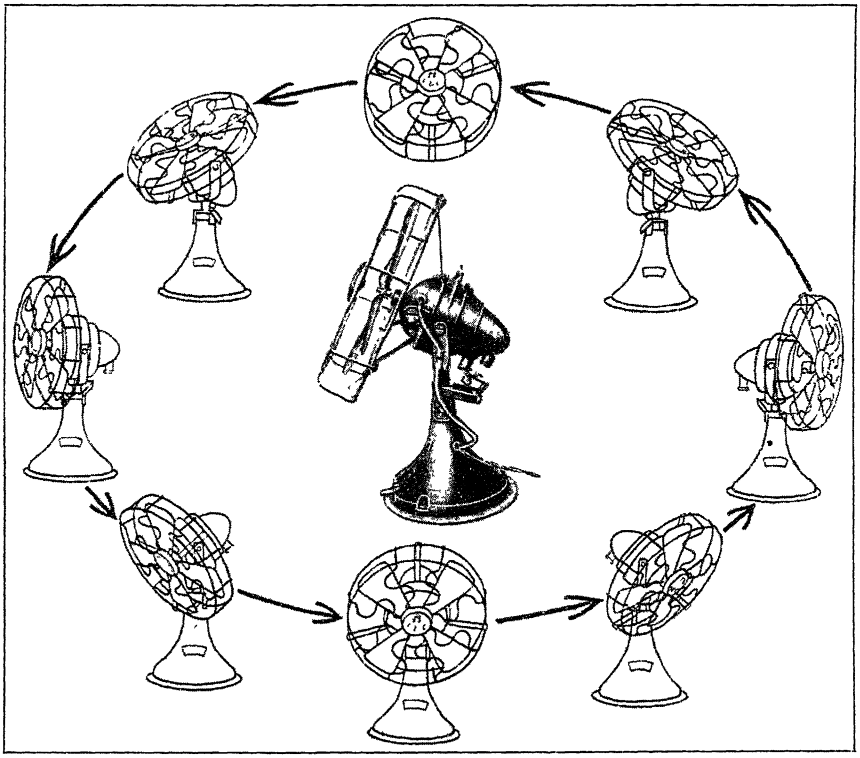

Fig. 1.—Showing successive positions of the fan in the course of a single gyration.

[1] The smooth progress of the investigation was greatly assisted by the help given by Mr. Sumner, the local weavers' secretary, and the thanks of the investigator are due to the weavers employed in the shed for their co-operation and opinions so freely given.

[2] Acknowledgments are due to the General Electric Company for providing the fans and for their technical advice and assistance throughout the investigation.

Fans with 12-in. blades were used with an approximate speed of 1,500–1,850 r p.m. They were suspended in pairs in the manner indicated in Fig. 2 at a height of 10 ft. above floor level, and were placed along the centre line of the shed so as to operate directly above the looms on each side of the main alley (Fig. 3). The position of the fans in relation to the looms is shown in Fig. 3.

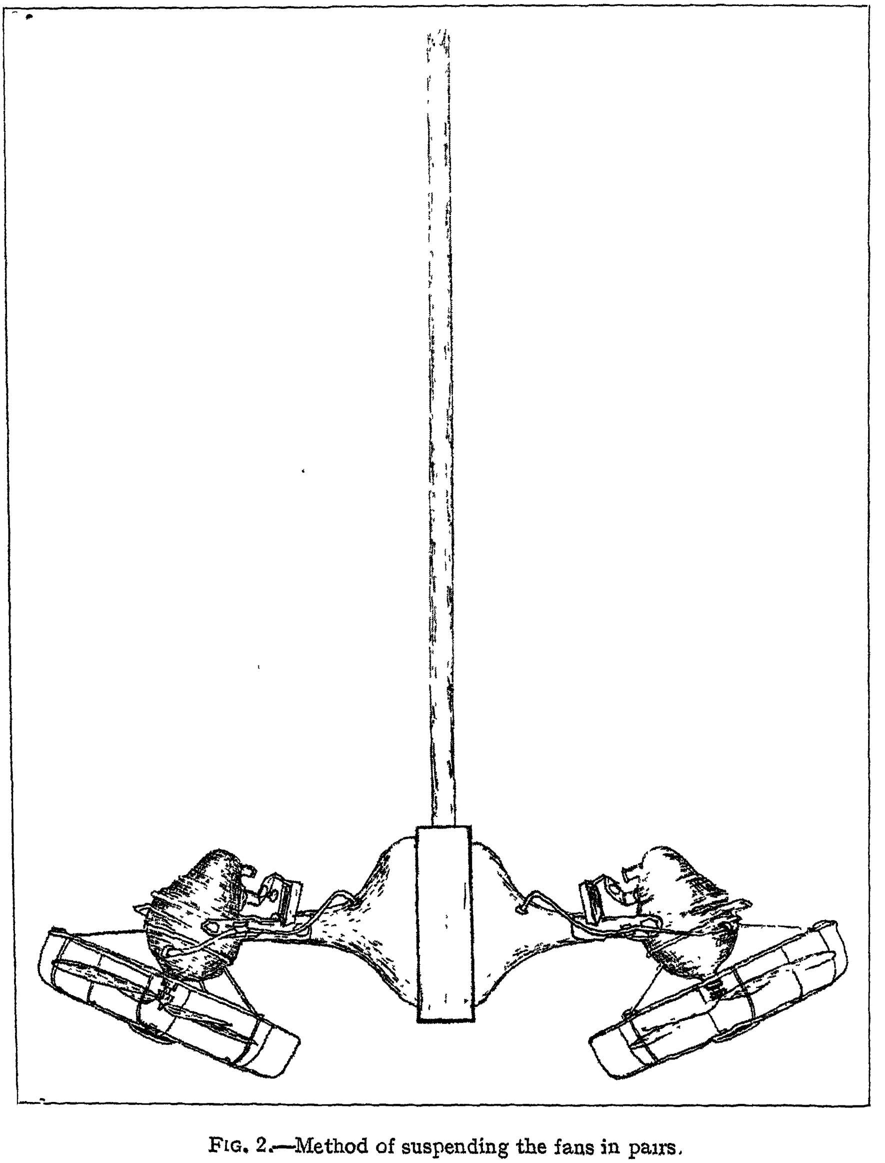

FIG. 2.—Method of suspending the fans in pairs.

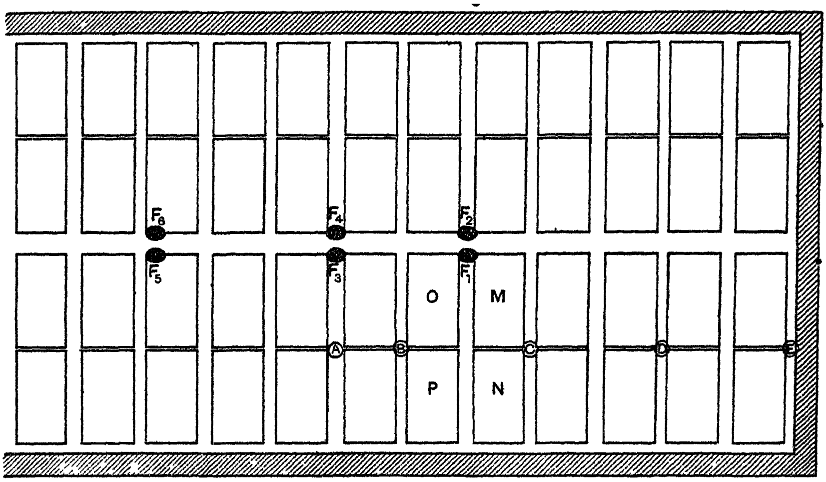

FIG 3.—Plan of shed showing position of fans with regard to looms and points at which observations were made.

In the earlier stages of this investigation, two pairs of fans (F_1 F_2 and F_3 F_4) were used, and these had an effective range over approximately half the shed. Later another pair was installed in the position F_5 F_6.

The cooling power of the air and rate of air movement under different conditions were obtained by means of the kata thermometer. Wet and dry bulb thermometer readings also were taken in the shed and outside in the shade.

In order to obtain a comparison of output with and without increased air movement, pick recorders were fixed to 44 looms in the part of the shed affected by the fans, and readings taken at hourly intervals throughout the day.

The procedure adopted in these experiments was to run the fans on alternate working days over a period of eight weeks (from 15th June to 7th August), except during the last two weeks, when they ran continuously for a week and were then stopped for a similar period. In this way the effects of increased air movement during a typical period in summer could be determined. Wet and dry kata readings were taken during alternate half-hours throughout each day. Wet and dry bulb thermometer readings were also taken at the same time. During the remaining half-hourly periods a record was made of the nature, number, and duration of all stoppages on each of four looms (M, N, P, O, Fig. 3) controlled by the same worker directly under the influence of the fans. These observations were necessary in order to determine the effect (if any) of increased air movement on the number of yarn breakages. Additional information relating to warp breakages was obtained from three weavers operating 12 looms. At the beginning of each spell of work these weavers were supplied with cards on which they recorded the number of warp threads broken immediately after the ends were pieced. The cards were collected at the end of each spell.

3. Results Obtained.

A. Effect of Fans on Atmospheric Conditions in the Shed.

(a) *Variations during a composite day.*

The effect of the fans on the atmospheric conditions in the vicinity of the operatives was determined by kata thermometer observations taken in different positions in the shed. The most representative position with regard to both the operatives and the fans was A (Fig. 3), i.e. opposite the middle fan in the central working position of the weaver. All the results obtained in this position at corresponding times on different days have been combined and averaged, and are given separately for the fans stopped and running in Table I and Fig. 4.

Table I.—*Comparison of atmospheric conditions in the same position with (a) fans stopped, (b) fans running.*

	Time.	Dry Bulb.	Wet Bulb.	Rel Hum.	Dry Kata	Wet Kata.	Evap Rate.	Air Vel.
Fans Stopped.	7.45– 8.15 ..	70·8	66·8	78·0	5·6	17·3	11·7	46
	8.45– 9.15 ..	73·3	69·4	79·5	5·1	15·6	10·5	48
	9.45–10.15 ..	75·0	71·1	79·5	4·7	14·7	10·0	47
	10.45–11.15 ..	76·5	72·3	78·4	4 3	14·1	9·8	46
	11.45–12.15 ..	77·8	73·4	77·5	4·0	13·7	9·7	46
	Average ..	74·7	70·6	78·6	4·7	15·1	10·3	47
	1.15–1.30 ..	77·2	73·2	79·2	4·0	13·4	9·4	41
	2.0 –2.30 ..	79·5	74·9	77·0	3·7	12·7	9·0	46
	3.0 –3.30 ..	80·3	75·5	76·5	3·5	12·4	8·9	46
	4.0 –4.30 ..	81·0	76·1	76·4	3·4	12·2	8·8	47
	5.0 –5.30 ..	81·5	76·5	76·0	3·2	12·0	8·8	46
	Average ..	79·9	75·2	77·0	3·6	12·5	9·0	45
	Daily Average	77·3	72·9	77·8	4·2	13·8	9·7	46
Fans Running.	7.45– 8.15 ..	71·9	67·9	78·9	7·5	21·5	14·0	139
	8.45– 9.15 ..	74·6	70·9	80·5	6·9	19·8	12·9	156
	9.45–10.15 ..	76·3	72·3	79·2	6·3	18·9	12·6	148
	10.45–11.15 ..	77·9	73·5	77·5	5·7	18·2	12·5	140
	11.45–12.15 ..	79·1	74·3	76·1	5·3	17·5	12·2	141
	Average ..	76·0	71·8	78·4	6·3	19·2	12·8	145
	1.15–1.30 ..	79·3	74·7	77·1	5·3	17·8	12·5	142
	2.0 –2.30 ..	80·5	75·7	76·6	5·1	17·1	12·0	152
	3.0 –3.30 ..	81·5	76·4	75·6	4·8	16·8	12·0	153
	4.0 –4.30 ..	82·1	76·7	74·4	4·5	16·4	11·9	147
	5.0 –5.30 ..	82·6	76·9	73·2	4·4	16·3	11·9	148
	Average ..	81·2	76·1	75·4	4·8	16·9	12·1	148
	Daily Average	78·6	73·9	76·9	5·6	18·0	12·4	147

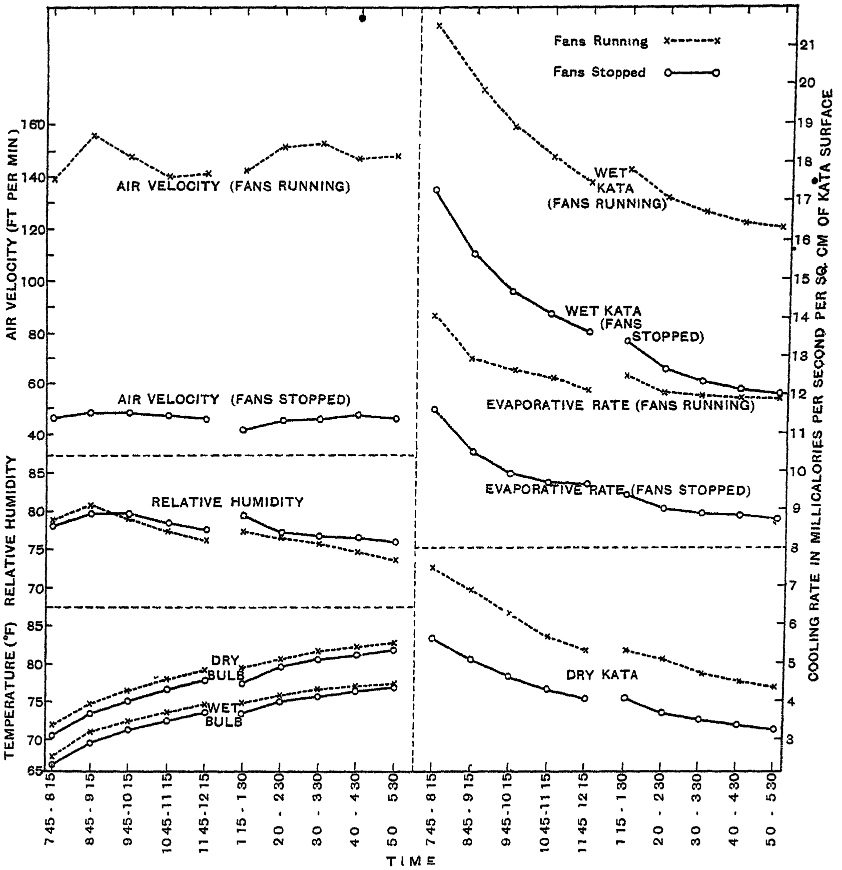

FIG. 4.—Comparison of atmospheric conditions at half-hourly intervals throughout the day with (*a*) fans running, (*b*) fans stopped.

The above results are based upon 65 observations in each composite half-hour when the fans were stopped, and on 50 observations when the fans were running.[1]

The table shows (*a*) the average dry and wet bulb temperatures and the relative humidity corresponding to these, (*b*) the dry and wet kata rates of cooling and the evaporative power of the air obtained from these, (*c*) the air velocity calculated from the dry kata readings.

The results show that the average rate of air movement was 46 ft. per minute when the fans were stopped, but was increased to 147 ft. per minute (an increase of 220 per cent.) when the fans

[1] The difference in the number of observations is due to the fact that the machinery broke down on some occasions when the fans were running, and readings in consequence were not taken

were running. The average cooling power of the air as shown by the dry kata was increased from 4·2 to 5·6 by the fans (an increase of 33·3 per cent.), while the evaporative power of the air on moisture at body temperature was increased from 9·7 to 12·4 (an increase of 28 per cent

As is usual in cotton-weaving sheds, the dry and wet bulb temperatures rise steadily throughout the day, but the rate of increase progressively decreases as the day proceeds. The relative humidity, on the other hand, tends to decrease slightly after about the first hour of work. The rate of air movement remains approximately constant, and both the dry and wet kata cooling rates accordingly decrease throughout the day, rapidly at first, but more slowly afterwards. This means, of course, that the cooling effect of the atmosphere is reduced as work proceeds, and the operatives are, in consequence, exposed to increasingly unfavourable atmospheric conditions.

The rate of cooling of the dry kata is due to the heat lost by radiation and convection. The additional cooling effect produced by evaporation is shown by the difference between the wet and dry kata readings. This is seen to decrease as the temperature rises, both when the fans are running and stopped. In the former case, however, the evaporative rate is appreciably greater than in the latter, thus the fans tend to keep the body cool, not only by promoting the dissipation of heat by means of the process of convection, but also by increasing the rate of evaporation of the moisture on the surface of the body.

It has been suggested that a minimum dry kata cooling rate of 6 and a minimum wet kata rate of 18 are desirable for workers engaged in sedentary occupations. It will be seen that, without fans, these standards were not attained in the present investigation. It is probable, however, that these minima, although ideally desirable, are not absolutely necessary for bodily comfort. A dry kata cooling rate of 5 and a wet kata of 15 appear to give fairly satisfactory conditions in a weaving shed. Except in the later part of the afternoon spell, these rates were exceeded when the fans were running.

(*b*) *Effect of fans at different temperatures.*

In the previous table, the average temperatures obtained when the fans were running are a little higher than when the fans were stopped, and consequently the kata cooling rates in the two series are not strictly comparable. In order to ascertain the cooling effect produced by the fans at different temperatures, the results obtained in position A have been arranged for differences in temperature of 2·5° F. and are given in Table II and Fig. 5.

TABLE II.—*Showing effect of fans at different temperatures.* (*Position A.*)

	Temp.		Dry Bulb.	Wet Bulb.	Rel. Hum.	Dry Kata.	Wet Kata.	Evap. Rate.	Air Vel.	No. of Obs.
Fans Stopped.	67·5–69·9	..	68·5	64·8	79·5	6·0	17·4	11·4	40	55
	70·0–72·4	..	71·5	67·9	80·5	5·4	16·1	10·7	46	45
	72·5–74·9	..	73·9	69·9	79·0	4·9	15·4	10·5	46	95
	75·0–77·4	..	76·4	72·2	78·3	4·4	14·5	10·1	50	125
	77·5–79·9	..	78·7	74·2	77·2	3·8	13·2	9·4	46	120
	80·0–82·4	..	80·8	76·0	76·8	3·4	12·3	8·9	46	115
	82·5–84·9	..	83·4	78·0	74·4	2·8	10·9	8·1	44	75
	85·0–87·4	..	86·5	80·0	70·5	2·2	9·2	7·0	42	15
Fans Running.	67·5–69·9	..	69·4	65·4	78·0	8·2	22·8	14·6	136	20
	70·0–72·4	..	71·8	67·7	78·3	7·5	21·4	13·9	136	25
	72·5–74·9	..	73·9	70·1	80·0	6·9	20·2	13·3	145	60
	75·0–77·4	..	76·4	72·1	77·9	6·2	19·1	12·9	146	110
	77·5–79·9	..	78·8	73·9	75·4	5·6	18·2	12·6	151	85
	80·0–82·4	..	81·1	76·5	77·6	4·9	16·8	11·9	153	95
	82·5–84·9	..	83·6	77·8	72·8	4·1	15·7	11·6	142	55
	85·0–87·4	..	86·4	80·2	71·6	3·1	14·0	10·9	128	30

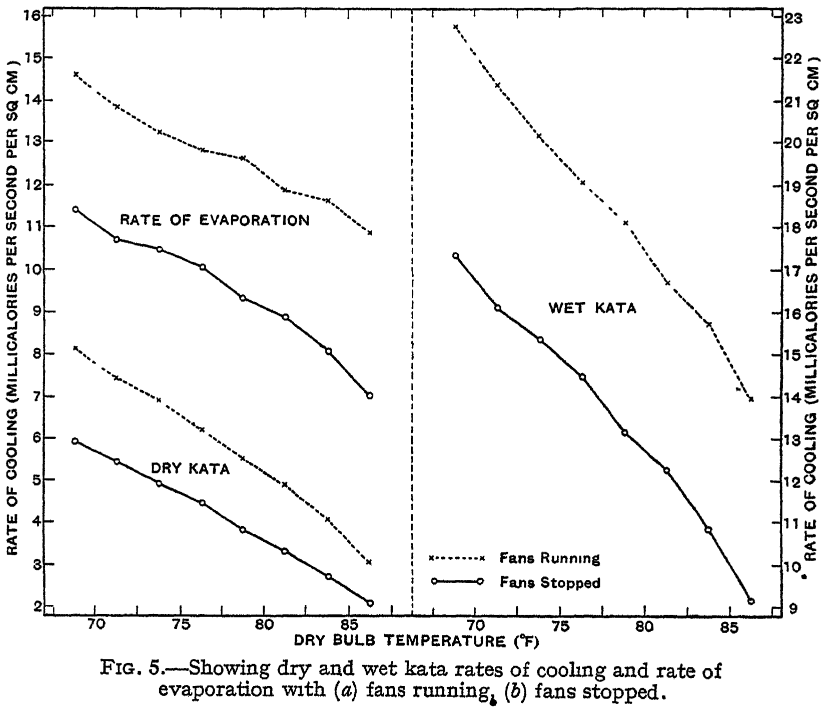

FIG. 5.—Showing dry and wet kata rates of cooling and rate of evaporation with (*a*) fans running, (*b*) fans stopped.

The results show that, as the temperature rises, both the dry and wet kata cooling rates fall at a fairly regular rate. It will also be noticed that there is a tendency for the dry kata cooling curves (with and without fans) to converge as the temperature rises, thus indicating that the increased air movement due to the fans is most effective at the lower temperatures. When the fans are stopped, the dry kata cooling rate never attains the suggested minimum of 6, and only exceeds the probably permissible minimum of 5 when the temperature is below 72·5° F. With the fans running, however, a cooling rate of 6 is exceeded whenever the temperature is below 77·5° F., and a cooling rate of 5 whenever the temperature is below 80° F. In other words, the air velocity of 146 ft. per minute produced by the fans makes the cooling effect (as shown by the dry kata) of a temperature of 77·5° to 80·0° greater than one of 70·0° to 72·5° without fans. To produce the same cooling effect at temperatures higher than 80·0°, more powerful fans would be necessary.

(c) *Effect of fans when running at different speeds.*

The fans used in these experiments were capable of being run at three different speeds, and the results obtained at each speed (position A) have been arranged according to temperature differences of 2·5° as shown in Table III.

TABLE III.—*Showing effect of fans when running at different speeds on atmospheric conditions in position A.*

Speed.	Temp. (° F.).	Dry Bulb.	Wet Bulb	Rel. Hum.	Dry Kata.	Wet Kata.	Evap. Rate.	Air Vel.
High.	70·0–72·4 ..	71·8	67·7	78·3	7·5	21·3	13·8	136
	72·5–74·9 ..	73·9	70·1	80·0	6·9	20·2	13·3	145
	75·0–77·4 ..	76·4	72·1	77·9	6·2	19·1	12·9	146
	77·5–79·9 ..	78·8	73·9	75·4	5·6	18·2	12·6	151
	80·0–82·4 ..	81·1	76·5	77·6	4·9	16·8	11·9	153
	Average ..	76·4	72·1	77·8	6·2	19·1	12·9	146
Medium.	70·0–72·4 ..	72·1	68·8	82·5	6·6	18·6	12·0	98
	72·5–74·9 ..	73·8	70·3	81·5	6·4	18·7	12·3	110
	75·0–77·4 ..	76·1	72·2	79·6	5·8	17·3	11·5	113
	77·5–79·9 ..	78·9	74·5	77·9	4·8	16·2	11·4	102
	80·0–82·4 ..	80·9	76·0	76·4	4·5	15·4	10·9	118
	Average ..	76·4	72·4	79·6	5·6	17·2	11·6	108
Low.	70·0–72·4 ..	71·3	67·8	80·8	6·4	18·3	11·9	80
	72·5–74·9 ..	73·8	70·2	81·0	5·9	17·2	11·3	85
	75·0–77·4 ..	76·0	72·0	79·0	5·3	16·1	10·8	85
	77·5–79·9 ..	79·2	74·5	76·6	4·5	15·2	10·7	90
	80·0–82·4 ..	81·5	76·3	75·2	4·0	14·2	10·2	93
	Average ..	76·4	72·2	78·5	5·2	16·2	11·0	87

The results show that the average air velocity due to the fans in position A is 146, 108, and 87 ft. per minute for the three speeds respectively. These produce a corresponding average rate of cooling of the dry kata of 6·2, 5·6, and 5·2. If a dry kata rate of cooling of 6 is considered necessary for weavers in humid sheds, then with the fans running at the highest speed this is possible up to a temperature of 77·5° F. When running at the medium and slowest speeds, the corresponding temperatures are 75·0° and 72·5°. If, however, the dry kata standard of 5 is accepted as a satisfactory minimum cooling rate, the temperatures for the respective speeds become approximately 82·5°, 80·0° and 77·5° F.

Similarly a wet kata cooling rate of 18 or more at humidities corresponding to those observed during this investigation is given by the fans at the highest speed up to a temperature of 80·0° at a medium speed until the temperatue reaches 75·0°, and at the lowest speed up to a temperature of 72·5°, while the corresponding temperatures for a wet kata cooling rate of 15 would be approximately 85·0°, 82·5°, and 80·0° respectively.

Thus, under the conditions in question, the fans should be run at the slowest speed until the temperature of the shed reaches 72·5°; they should then be switched on to the medium speed until a temperature of 75·0° is reached, after which they should be run at the highest rate.

(*d*) *Effect of fans on air movement in other positions.*

In addition to the readings taken in the most representative position (A), observations were made in other positions (B, C, D, and E, Fig. 3), at increasing distances from the fans. They are given in Table IV.

TABLE IV.—*Showing effect of fans on rate of air movement in different positions.* (*Fans at highest speed.*)

Position.	Air Velocity.
A	146
B	121
C	84
D	52
E	48

The average air velocity in these positions when the fans were stopped was 46 ft. per minute.

The results show the general decrease in the rate of air movement as the distance from the fans increases. Obviously, position A is the only one which is fully affected by all three fans, and it is therefore representative of the results which would be

obtained if more fans were fixed in the same line throughout the shed. Position B is primarily affected by two fans, while only one fan has any appreciable effect in positions C, D, and E. The influence of the fans in positions D and E is very slight, but is appreciable in position C (about 9 ft. from the nearest fan). In general, it may be said that the three fans fail to have any significant effect beyond a distance of 27 ft. from the nearest fan.

(e) Experiments with other fans.

In addition to the main experiments previously described, a small fan of the "Polar Cub" type, having 8-in. blades, was tried. This fan was placed about 3 ft. above floor level, and acted in a slightly upward direction towards the weaver in the manner indicated in Fig. 6.

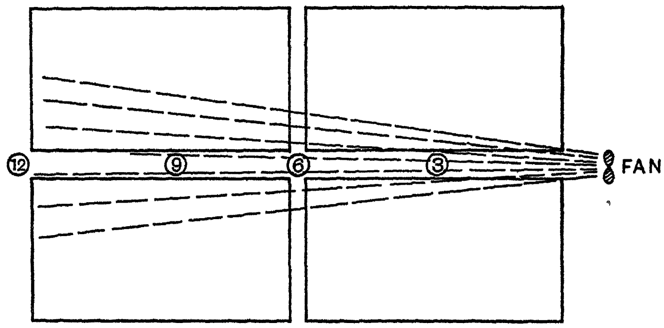

FIG. 6.—Showing position of fan in relation to looms.

The fan was fixed, and, unlike the other fans, produced a continuous current in the same direction. Since, however, the weaver was not stationary, but moved from one loom to another, she was constantly exposed to a varying rate of air movement.

The results obtained at different distances from the fan are given in Table V.

TABLE V.—*Showing results obtained at different distances from a small fan of the fixed type.*

Dist. from fan (ft.).	Dry Bulb.	Wet Bulb.	Rel. Hum.	Dry Kata.	Wet Kata.	Evap. Rate.	Air Vel.
3	75·3	71·6	80·6	9·3	18·1	8·8	335
6	74·5	71·0	81·5	8·5	17·2	8·7	246
9	74·6	71·1	81·5	6·2	14·8	8·6	114
12	74·8	71·0	80·0	5·8	13·9	8·1	96

The above readings were taken during the dinner hour when the machinery was stopped, and the average air velocity without the fan was 20 ft. per minute. The distance from the fan was taken horizontally and observations made 5 ft. above floor level.

The results show that the fan has a strong local effect, and is much more effective over the limited area than the larger fans used in the main investigation. The fan is not only quite adequate for the purposes of the weaver in charge of the four looms in question, but its influence extends considerably beyond them. The advantages of a single fan of this type are that it gives a strong local air current, can be placed so as to operate horizontally above the warps, and can be used at the discretion of the individual weaver.

Other experiments were also carried out with an overhead fan of the type shown in Fig. 7. In this case the fan was fixed to a beam 13 ft above floor level. The blades were 24 in. in diameter and gave 550 r.p.m. in a horizontal plane. An interrupting device was introduced into the electric circuit, which caused a periodic variation in the number of fan revolutions.

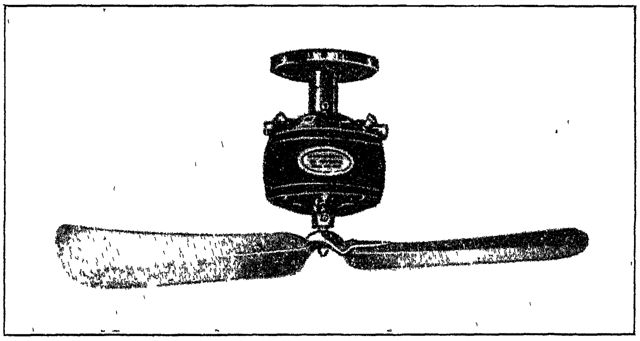

FIG. 7.

The period was 13·5 seconds, i.e. the revolutions reached a maximum and then decreased until they almost ceased, once every 13·5 seconds. In this way, a varying air current was produced which was most effective in a position directly underneath the fan (i e. in the middle of the four looms controlled by the weaver concerned). Readings were taken 4 ft. above floor level in this position, and also at the same level 3 ft. and 6 ft. away, during the dinner hour when the machinery was stopped, and the average air velocity without the fan was 20 ft. per minute. The results obtained are given in Table VI.

TABLE VI.—*Showing results obtained in different positions underneath a fan revolving at a varying speed.*

Position.	Dry Bulb.	Wet Bulb.	Rel. Hum.	Dry Kata.	Wet Kata.	Evap. Rate.	Air Vel.
Directly underneath	77·1	72·3	75·8	6·6	16·9	10·3	187
3 ft. away	76·5	72·5	79·2	5·0	13·4	8·4	79
6 ft. away	77·5	73·0	77·0	4·7	12·1	7·4	75

Thus an appreciable increase in the rate of air movement is produced by the fan, especially in the position directly underneath. The intermittency of the fan, of course, gives a much lower average air velocity than would be obtained if the fan were running at maximum speed throughout, but the beneficial effects of a variable air movement are believed to be greater than those produced by a constant air velocity. A fixed fan of this type is only effective over an area covered by four looms or one weaver, but it possesses the advantages of intermittency and individual control.

B. Effect of Fans on Warps.

The effect of increased air movement produced by the fans upon the frequency of warp breakages has been determined from records obtained from 16 looms over periods varying from 30 to 109 hours for each loom. The results obtained from looms 1 to 4 (Table VII) were recorded by the investigators during alternate half-hours throughout the day, while the others were noted by the weavers in each spell of work.

The results show the average number of loom-stoppages per hour due to warp breakages, and also the average number of threads broken in the same unit of time. In each case the warp remained unchanged throughout the period of observation.

It will be remembered that during the greater part of the investigation, the fans were run on alternate days, but towards the end they ran continuously for a week, after which they were stopped for a similar length of time. Although the two periods under comparison (i.e. days on which the fans were running and days on which they were stopped) covered approximately the same range and distribution of temperature and humidity, the more precise method of arranging and averaging the results for same ranges of temperature and humidity in the two series has been adopted. For example, all the results obtained within a temperature range of $80 \cdot 0°$ to $82 \cdot 5°$ F. and a relative humidity of $70 \cdot 0$ to $72 \cdot 5$ per cent. were combined and averaged for each loom separately when (*a*) the fans were running and (*b*) the fans were stopped. The same procedure was adopted for all the other possible combinations of temperature and humidity. Thus, the final averages (obtained without weighting by the number of observations in each shed) in the two series relating to the results obtained with and without increased air movement are based upon similar conditions of temperature and humidity, and consequently the only significant remaining variable is air movement. The results so obtained are given in Table VII.

TABLE VII.—*Showing average number of loom stoppages due to warp breakages and average number of warp threads broken per hour with (a) fans stopped, (b) fans running.*

	Fans Stopped			Fans Running.		
Loom No.	Hours Observed.	Loom Stoppages.	Warp Breakages.	Hours Observed.	Loom Stoppages.	Warp Breakages.
1 ..	43·5	2·58	4·06	42·0	2·24	2·92
2 .	52·0	1·28	1 60	57·5	1·16	1·24
3 ..	71·5	1·72	3·06	70·5	1·74	2·58
4 ..	44·0	2·20	3·06	45·0	2·18	3·28
5 ..	100·5	4·54	6 25	87·5	4·04	5·47
6 .	109·5	2·93	3·17	96·5	2·29	2·59
7 ..	109·5	0·34	0·38	96·5	0·29	0·33
8 ..	70·0	0·79	0·99	61 5	0·95	1·36
9 ..	92·0	0·80	1·23	78·5	0·73	0·98
10 ..	79·0	1·23	1·94	78·5	1·05	1·50
11 ..	79·0	1·14	1·86	78·5	1·04	1·93
12 ..	79·0	1·75	3·06	78·5	1·47	2·92
13	44·0	1·30	1·69	43·5	0·91	1·12
14 ..	44·0	3·46	5·15	43·5	3·51	5·49
15 ..	30·5	0·82	1·11	30·5	0·84	1·30
16 ..	57·0	0·51	0·64	40·0	0·71	0·80
Average ..		1·71	2·45	—	1·57	2·24

The above results show that with the fans running there was a decrease in the number of loom stoppages due to warp breakages and also in the number of threads broken in approximately two-thirds of the number of looms observed, and an increase in the remaining third. In no case, however, is the difference between corresponding averages in the two series statistically (strictly speaking) significant,[1] and is probably attributable to the chance influence of other factors. It is, nevertheless, important to note that no increase in the number of warp breakages is associated with the increased air movement produced by the fans, so that the fans evidently do not have a significant drying effect on the warps. This may be due to the fact that the rate of evaporation of moisture in the warps depends upon the amount of water vapour in the surrounding air.[2] This amount is certainly not

[1] i e. the difference between any two means is always less than three times its probable error

[2] The rate of evaporation of moisture from the body depends, on the other hand, upon the amount of water vapour in the air in immediate contact with the body, which is usually almost saturated at body temperature (c. p. 5).

reduced by the fans, but, on the contrary, is increased, because the fans drive down the more highly saturated air from the vicinity of the humidifiers towards the warps, as is shown by the following observations :—

Position.	Fans Running.			Fans Stopped.		
	Dry Bulb.	Wet Bulb	Rel Hum.	Dry Bulb.	Wet Bulb.	Rel. Hum.
14 ft. above floor level ..	79·5	73·9	72·6	76·9	74·0	84·5
4 ft. above floor level ..	79·2	73·7	73·0	75·8	71·4	77·3

Probably in all humid sheds the air near the roof is appreciably hotter and more moist than that surrounding the warps; a condition which is clearly economically wasteful.

C. Effect of Fans on Output.

The effect of the fans on the amount of cloth produced has been shown by the readings taken from the pick recorders attached to the looms. These readings, which were taken at hourly intervals throughout the period of the investigation, enable a comparison to be made between the output obtained when the fans were running and also when stopped. An accurate comparison is only possible when (*a*) the temperature, (*b*) the relative humidity and (*c*) the position of the spell in the week are approximately the same in the two series. The last factor is important, because incentives to work and working capacity vary at different times during the week. The results have accordingly been arranged so that the three factors in question were approximately the same in the two comparative series, and consequently the only significant variable was the rate of air movement. This was achieved by selecting corresponding spells in different weeks when the average temperature and humidity were approximately the same, but in the one case the fans were running, while in the other they were stopped.[1] The results are given in Table VIII and Fig. 8.

[1] e.g. a spell with an average temperature of 75·0 to 77·5° F. and a relative humidity of 80·0 to 82·5 per cent. when the fans were running would be compared with a similar spell when the fans were stopped, providing they happened to occupy the same position in the week. This method necessarily reduces the number of spells available for comparative purposes, but increases the reliability of the results. Thus, in the following table, the results obtained in corresponding spells when the fans were (*a*) stopped and (*b*) running are directly comparable.

TABLE VIII.—*Showing hourly variations in output (in picks) obtained from 44 looms when fans were (a) stopped, (b) running.*[1]

FANS STOPPED.						FANS RUNNING.					
Day.	8.0–9.0	9.0–10.0	10.0–11.0	11.0–12.0	Avg	Day.	8.0–9.0	9.0–10.0	10.0–11.0	11.0–12.0	Avg
1. Thu. ..	7800	7792	7818	7736	7787	1 Thu. ..	7974	7480	8084	8167	7926
2. Thu. ..	7344	7353	6918	7333	7237	2 Thu ..	7576	7095	7518	7686	7468
3. Wed. ..	6423	6625	7141	7684	6968	3 Wed ..	6512	6437	7073	7023	6761
4. Thu. ..	6800	6993	7566	6824	7046	4. Thu ..	6440	7479	7553	7207	7170
5. Mon. ..	6467	6164	6551	6315	6372	5. Mon. ..	6102	7172	6961	7356	6898
6. Tue. ..	7221	7339	7493	7519	7393	6. Tue ..	7966	7554	8400	7300	7805
7. Tue. ..	7254	7202	7940	7256	7413	7. Tue. ..	7627	6848	7469	7091	7259
8. Fri. ..	6724	7254	6906	7524	7102	8 Fri. ..	6603	7493	7940	7375	7353
9. Fri. ..	6418	7345	7653	7181	7149	9 Fri ..	6967	7249	6998	6202	6854
10. Mon ..	5837	7368	8064	7886	7289	10. Mon ..	5986	6521	8678	7186	7093
11. Fri. ..	6661	7136	7229	7214	7060	11 Fri. ..	6424	7957	7558	8005	7486
Avg. ..	6814	7143	7389	7316	7165	Avg ..	6925	7208	7657	7327	7279
Day.	1.15–2.15	2.15–3.15	3.15–4.15	4.15–5.15	Avg.	Day	1.15–2.15	2.15–3.15	3.15–4.15	4.15–5.15	Avg.
12. Wed. ..	6943	8118	7400	7665	7531	12 Wed. ..	7165	7850	7750	7847	7653
13. Tue ..	7319	7328	7597	7170	7354	13 Tue ..	7461	7884	7800	7619	7691
14. Mon. ..	6892	7818	7005	8027	7435	14 Mon. ..	7382	8287	7476	7784	7732
15. Fri. ..	6799	6132	6718	6254	6476	15. Fri. ..	5781	6281	6803	7169	6508
16. Thu ..	6634	6569	6295	7008	6627	16 Thu ..	6779	7267	6552	6565	6791
17. Mon. ..	6684	7091	6430	6284	6622	17 Mon. ..	6611	7197	6740	7330	6969
18. Tue. ..	6692	7039	7562	7447	7185	18 Tue ..	6950	7480	7253	6843	7132
19. Fri. ..	7050	6493	6613	6490	6662	19 Fri. ..	6837	6405	6212	6098	6388
20. Mon. ..	7075	7512	7553	7061	7300	20. Mon. ..	6960	7458	7703	7834	7489
21. Thu. ..	6349	6985	7054	6781	6792	21 Thu. ..	7387	7588	7844	7682	7625
Avg. ..	6844	7109	7023	7019	6998	Avg. ..	6931	7370	7213	7277	7198

[1] The hours of work were from 7.45 to 12.15 and from 1.15 to 5.30, but the output in the quarter-hour periods at the beginning and end of the spells has not been included in the Table because of irregularities in the times of starting and stopping work.

The averages, on the whole, indicate a somewhat higher output on the days when the fans were running than on the days when the fans were stopped. The average increase is 1·6 per cent. in the morning spell, and 2·9 per cent. in the afternoon spell. Since the only significant variable factor in the two series under comparison is the rate of air movement, the observed differences in output must be attributed to the effect of the fans. It has already been shown that the fans have no appreciable effect upon the frequency of warp breakages, consequently the increased output obtained when the fans were running must be due to the beneficial effects of increased air movement upon the weavers concerned, enabling them to deal with the breakages more quickly.

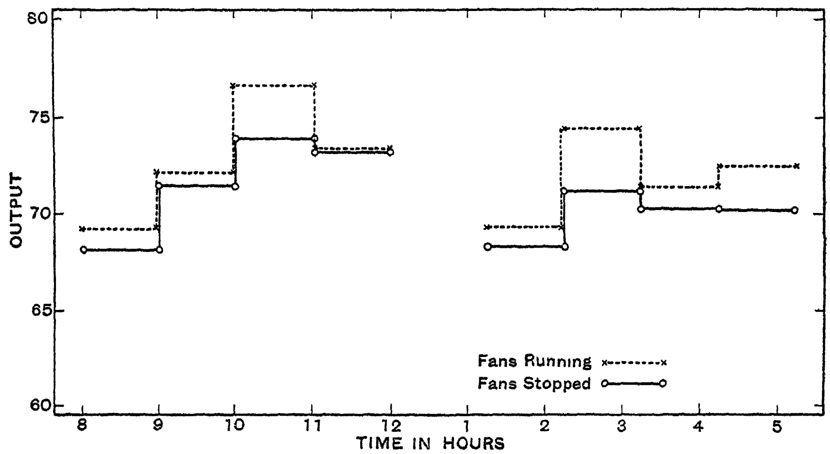

FIG. 8.—Hourly variations in output during a composite day with (*a*) fans running, (*b*) fans stopped.

The beneficial effect of the fans upon the weavers appears to be most marked in spells when the temperature or humidity is high. This is illustrated in Figs. 9 and 10, which compare the outputs with the fans running and the fans stopped (*a*) over two spells with an average humidity of 83·7 per cent., and (*b*) over two spells with a temperature of 86·4° at corresponding times in different weeks.

In these cases, not only is the average output in each spell higher with the fans running, but it also tends to be maintained at a higher level throughout the spell, and is unusually high in the last complete hour of work. It would appear that when the fans are stopped the enervating effects of a high temperature or humidity cause a decrease in the rate of working, especially in the latter half of the spell, but when the fans are running working ability remains practically unimpaired.

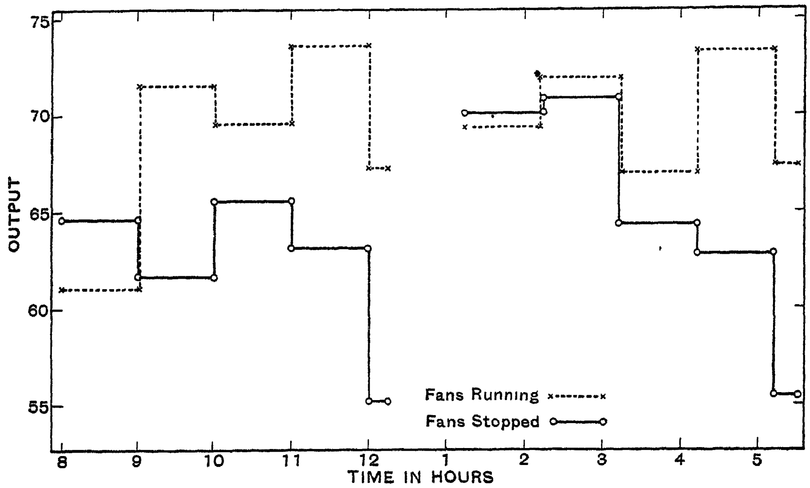

FIG. 9—Hourly variations in output on days of high humidity (83·7 per cent.) with (*a*) fans running, (*b*) fans stopped

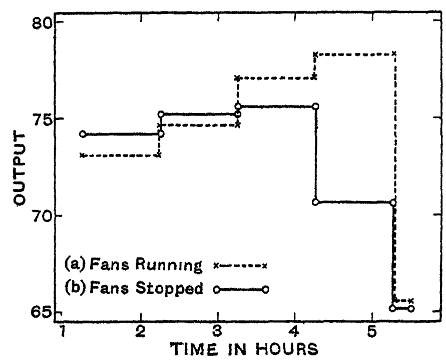

FIG. 10—Hourly variations in output during an afternoon spell, (*a*) fans running, (*b*) fans stopped. (Average temperature = 86·4° F)

D. Effect of Temperature and Humidity on Warp Breakages.

It is usually asserted that a high temperature and relative humidity are necessary for the manufacturing process in humid weaving sheds. The number of warp breakages is said to vary inversely with these two factors, and some evidence in support of this contention has already been adduced.[1] Additional information bearing on this question can be obtained from the present investigation, since breakage observations and temperature readings were simultaneously recorded throughout the experimental period. The results obtained deal with two groups of looms. Group 1 consists of four looms on which breakage observations were made every alternate half-hour by the investi-

[1] *See*, for instance, Report No. 23 of the Industrial Fatigue Research Board.

gators. Group II includes eight looms on which breakages were observed by the weavers and recorded on the cards supplied for that purpose. In every case the warp remained unchanged during the observational period.

(*a*) *Effect of relative humidity.*

The results presented in this section have been arranged so as to show the average number of loom stoppages due to warp breakages, together with the average number of warp threads broken per hour for differences in relative humidity of 2·5 per cent. at a temperature of 75° to 80° F. This temperature range was chosen because it provided the greatest number of observations. The results are given in Table IX and Fig. 11.

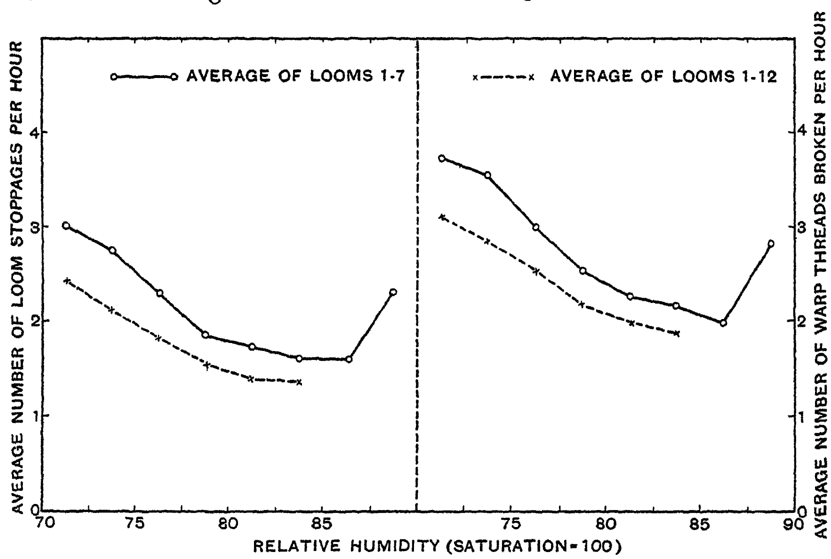

FIG. 11.—Showing average number of loom stoppages due to warp breakages, and threads broken per hour, corresponding to differences in relative humidity of 2·5 per cent.
(Temperature 75–80° F.)

The results show that, in general, the number of loom stoppages due to warp breakages and the actual number of warp threads broken decrease as the relative humidity increases. The average percentage decrease in the number of loom stoppages for each successive increase of 2·5 per cent. in relative humidity is 11·1, while the corresponding figure for the number of warp threads broken is 9·6. There is also an indication that the rate of decrease is not uniform, but becomes progressively less as the relative humidity increases. The results obtained from looms 1 to 7 further suggest that beyond a certain point (corresponding to a relative humidity of about 87·5 per cent.) the number of warp stoppages and ends broken begins to increase with an increase in relative humidity. The number of cases on which this indication is based is, however, so small that the suggestion must be accepted with great reserve.

TABLE IX.—*Showing average number of loom stoppages due to warp breakages, and threads broken per hour, corresponding to differences in relative humidity of 2·5 per cent. (Temperature 75°–80° F.).*

Relative Humidity.		70·0–72·4			72 5–74·9			75 0–77 4			77 5–79·9			80·0–82 4			82·5–84·9			85·0–87 4			87·5–89·9		
Loom Number.		Hours Observed.	Loom Stoppages.	Ends Broken.	Hours Observed	Loom Stoppages.	Ends Broken.	Hours Observed.	Loom Stoppages	Ends Broken.	Hours Observed.	Loom Stoppages.	Ends Broken.	Hours Observed.	Loom Stoppages.	Ends Broken	Hours Observed	Loom Stoppages	Ends Broken.	Hours Observed.	Loom Stoppages.	Ends Broken.	Hours Observed.	Loom Stoppages.	Ends Broken.
	1	1·50	3 34	4·66	4·50	3·12	4·00	10 00	2 60	3·30	7·00	2 42	3 00	8 00	1·75	2 50	3 5	1 72	2 00	2·00	1·50	2·50	1·00	5·00	6·00
Group	2	1 50	2 66	3·34	5 00	2 60	3 20	10·50	1 14	1 62	9 50	0 74	0·95	10·00	1·10	1·40	6 0	0·84	1·00	2 50	0 80	0 80	1·50	0·00	0·00
	3	3·50	3 14	4·00	11 50	2 96	3 92	16 50	2 12	3 08	13·50	1·70	2·14	11·00	1 55	2·37	6 0	1 50	2 50	2 00	1·00	2 00	2 00	2 50	3 50
	4	1·50	3·34	4 00	4 50	2·66	3 78	9 50	2 22	2·94	7 00	1 86	2 86	8 00	1 50	2 37	4·0	2 25	3 25	1 50	2 66	2·66	0·50	2 00	2 00
	5	4 25	4·94	6·12	21·50	4 70	6·19	21 25	4 52	6 22	13 50	4 53	6 74	8·75	4 12	5 14	9·0	2 78	3 67	4 25	3·06	3·76	4 25	4·00	5·42
	6	4·25	3·53	3 53	30 50	2 98	3 31	21·25	3·11	3 43	13·50	1 48	1 78	8·75	1 60	1 80	9 0	2·00	2 56	4 25	1 88	1 88	4 25	2 36	2 59
	7	4 25	0 40	0·40	30 50	0·33	0 36	21·25	0·33	0·33	13·50	0·15	0·15	8 75	0 34	0 34	9 0	0 11	0·11	4 25	0 24	0·24	4 25	0·24	0 24
Group	8	4·25	1·88	2 12	17 00	1·30	1 41	17 00	0 47	0 59	9 00	0·55	0·89	17 75	0·45	0 68	4 5	1·11	1 78	—	—	—	—	—	—
II	9	4·25	0 94	0·94	30·50	0·85	1·18	17·00	0 88	1 30	13 50	0 74	1·40	17 75	0·80	1 03	4 5	0 89	0·89	—	—	—	—	—	—
	10	4·25	1·64	1·88	26·25	1·33	1·98	17 00	1·18	1·76	13 50	1 04	1 48	17·75	0 90	1·29	4 5	0 67	0·67	—	—	—	—	—	—
	11	13 00	1·31	2 08	26 25	0 95	1·72	17 00	1·18	2·24	22·50	1 24	1·64	17 75	1·01	1·97	4·5	0 89	1·56	—	—	—	—	—	—
	12	13 00	2 00	4·08	26·25	1·72	3 01	17 00	1·94	3·41	13·50	1·92	2·96	17 75	1·52	3 04	4 5	1·34	2 44	—	—	—	—	—	—
Average																									
Looms 1–7 ..			3·05	3·72	—	2·76	3·54	—	2 29	2 99	—	1·84	2·52	—	1·71	2·27	—	1 60	2·16	—	1·59	1 98	—	2 30	2·82
Looms 1–12 ..			2·43	3·10	—	2·12	2·83	—	1 81	2·52	—	1 53	2·17	—	1 39	1·99	—	1·34	1·87	—	—	—	—	—	—

A consideration of the results obtained from each separate loom reveals the existence of certain discrepancies and irregularities, but these are only to be expected having regard to the variations in the quality and strength of the yarn at different places in the same warp.

(*b*) *Effect of Temperature.*

In order to determine the relation between temperature and warp breakages, the average number of loom stoppages due to warp breakages and the number of warp threads broken per hour have been ascertained for differences in temperature of 2·5° F. at a relative humidity of 75 to 80 per cent. The results are given in Table X and Fig. 12.

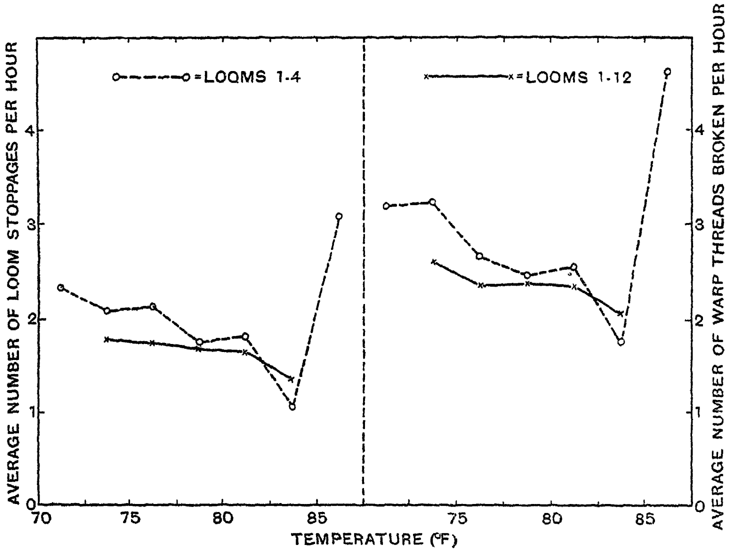

FIG. 12.—Showing average number of loom stoppages due to warp breakages, and threads broken per hour, corresponding to differences in temperature of 2·5° F.
(Relative humidity 75 to 80 per cent.)

In this case the average of the results obtained from looms 1 to 4 has been given in addition to the averages for all the looms combined because they extend over a greater temperature range.

The results show that, on the whole, temperature has a slight, but positive, effect upon the warp as shown by the number of loom stoppages due to warp breakages and the number of warp threads broken. The average percentage decrease in the number of loom stoppages for each successive increase of 2·5° F. in temperature is 6·3, while the corresponding value for the number of warp threads broken is 5·5. Within the practical limits of variation, therefore, temperature is less effective in this respect than relative humidity.

TABLE X.—*Showing average number of loom stoppages due to warp breakages, and threads broken per hour, corresponding to differences in temperature of* 2·5° F. (*Relative humidity*, 75–80 *per cent.*)[2]

Temp.	70 0–72·4			72 5–74 9			75·0–77 4			77 5–79 9			80 0–82 4			82·5–84·9			85·0–87·4		
Loom Number	Hours Observed.	Loom Stoppages.	Ends Broken.	Hours Observed.	Loom Stoppages.	Ends Broken.	Hours Observed.	Loom Stoppages.	Ends Broken..	Hours Observed	Loom Stoppages.	Ends Broken.	Hours Observed	Loom Stoppages.	Ends Broken	Hours Observed	Loom Stoppages.	Ends Broken.	Hours Observed.	Loom Stoppages.	Ends Broken.
Group I 1	2 0	3·50	4 00	5·0	2·00	2·60	6 5	3 24	4 00	10 5	2·19	2 66	11 5	2·18	2 52	2·5	2·40	3 60	2 5	3·20	3·60
2	2·0	1 00	1 00	2 5	1 60	1 60	7 5	0 66	0 80	12 5	1·12	1 60	10 0	1·60	1 70	3 5	0·58	0 58	3·5	2 00	2·00
3	5·5	3 28	5 28	7·0	1·72	3 14	15 5	1 81	2 26	14 5	2 00	3 10	11 0	1·91	3 46	2 5	0·80	2·40	2·5	4 40	8·80
4	2 0	1 50	2·50	2 0	3 00	5 50	6 5	2 77	3 54	10 0	1·60	2 50	8 0	1 50	2 50	2 5	0 40	0·40	3 0	2·67	4 00
Group II 5	—	—	—	36 0	4 56	6 22	21·75	4 50	6 30	13 0	4 39	6·30	13 0	4 78	6 18	12 75	3 60	4 62	—	—	—
6	—	—	—	36 0	3·28	3 69	21 75	2 25	2·53	13 0	2 16	2 38	13 0	2 31	2·54	17 0	2 29	2·59	—	—	—
7	—	—	—	36 0	0 45	0 56	21·75	0 09	0 09	13·0	0 54	0 54	13 0	0 00	0 00	17·0	0 59	0·65	—	—	—
8	—	—	—	27 0	0·74	0 85	17 25	0 46	0·70	8 75	0·57	0 69	13 0	0·69	1·08	8 5	1·41	2 11	—	—	—
9	—	—	—	27 0	0 59	0 74	21·75	0 83	1 33	8·75	0 80	1 37	13 0	0 77	0 93	17·0	0·82	1·76	—	—	—
10	—	—	—	27 0	0 96	1 56	21·75	1·14	1 70	8 75	0 92	1 14	13 0	0 98	1 23	4 25	0·94	1 41	—	—	—
11	—	—	—	27 0	1·04	1·74	21 75	1 28	1 93	8 75	1 71	2 40	13 0	1·08	2 15	4 25	0 94	2·35	—	—	—
12	—	—	—	27 0	1·26	3 00	21 75	1 84	2 98	8·75	2 17	3 76	13 0	2 15	3·85	4 25	1 41	2·13	—	—	—
Average.																					
Looms 1–4		2 32	3 19	—	2 08	3 21	—	2·12	2·65	—	1 73	2·46	—	1·80	2 54	—	1 05	1 74	—	3 07	4·60
Looms 1–12 .		—	—	—	1·77	2 60	—	1 74	2 35	—	1·68	2 37	—	1 66	2·34	—	1·35	2 05	—	—	—

[1] In each temperature range the relative humidity approximated to 77·5 per cent.

As in the case of relative humidity, there is some slight indication to show that when the temperature exceeds about 85° F. the number of loom stoppages and threads broken may begin to increase (looms 1 to 4), but here again the fewness of the observations at the higher temperature precludes any definite pronouncement on this point.

Fluctuations in the results obtained from each separate loom are much more marked than those of the previous table, and further illustrate the relatively smaller effect of temperature, as compared with relative humidity, upon the warps.

E. Effect of Humidity and Temperature on Output.

The effect of relative humidity and temperature on productive efficiency has been determined from the pick recorder readings obtained from 44 looms on days having different atmospheric conditions. The unit adopted for comparative purposes was the average hourly output per day of $8\frac{3}{4}$ hours. Since the incentives to work and working ability vary on different days of the week, it has been necessary to apply a correction to the observed daily output according to the day of the week on which it was obtained. This has been achieved by expressing the average hourly output recorded on any one day in terms of the average hourly output over the whole period of the investigation, according to the method described on p. 31. In this way the effect of disturbing subjective variations has been rendered constant, and the only significant remaining variables are temperature and relative humidity.

(a) *Effect of relative humidity.*

To determine the effect of relative humidity on output, the results obtained on days when the average temperature was from 75° to 80° F. have been arranged according to differences in relative humidity of 2·5 per cent. This procedure, by utilising a practically constant temperature, leaves relative humidity as the only remaining variable of any importance. The results so obtained are given in Table XI.

Table XI.—*Showing average hourly output (in picks) on days of different relative humidity. (Average daily temperature, 75° to* 80° F.)

Relative Humidity.	No. of Days.	Average Hourly[1] Output.
75·0–77·4	7	7013
77·5–79·9	5	7163
80·0–82·4	4	7021
82·5–84·9	3	6832

[1] The means for the ranges 77·5–79·9 and for 82·5–84·9 differ significantly from the general mean. The output corresponding to the other temperature ranges do not. (Tested by Students' Tables in Biom. XI.)

The above results show that the highest output is obtained with a relative humidity of 77·5 to 80 per cent., but beyond this degree of saturation a decrease in output occurs. Since the frequency of warp breakages decreases with an increase in relative humidity (Table IX), it follows that, beyond a saturation of 77·5 to 80 per cent., the rising humidity has an increasingly unfavourable effect upon the working activities of the weavers. Thus, as far as the quantitative aspect of production is concerned, the high humidities frequently observed in this shed appear to be unnecessary and undesirable.

(*b*) *Effect of temperature.*

A similar method of procedure has been adopted in order to determine the effect of temperature on output. Thus the results obtained on days when the relative humidity was 75 to 80 per cent. have been arranged according to temperature differences of 2·5° F., and are given in Table XII.

TABLE XII.—*Showing average hourly output on days of different temperatures.* (*Average relative humidity,* 75 *to* 80 *per cent.*)

Temperature.	No of Days.	Average Hourly[1] Output.
72·5–74·9	3	7335
75·0–77·4 .. .	8	7080
77·5–79·9	4	7067
80·0–82·4	4	7075
82·5–84·9	2	6995

[1] The first three values in the table, but not the last two, show a significant difference from the general mean. (Students' Tables, Biom. XI.)

The above results show that, on the whole, temperature has very little effect on productive efficiency when the relative humidity is from 75 to 80 per cent. Since a rising temperature has a favourable effect upon the frequency of warp breakages (Table X), it is evident that the higher temperatures tend to have an adverse influence upon working activity. As in the case of relative humidity, there appears to be no economic value in very high temperatures.

F. OPINIONS OF THE WEAVERS.

When the nature and purposes of the investigation were being explained to the weavers prior to the beginning of the investigation, three of the older women operatives raised objections to the installation of fans on the grounds that they would create draughts. Further questioning elicited the fact that the opinions

were based upon traditional beliefs, and not upon actual experience. After a little additional explanation, the weavers in question agreed to give the fans a trial. It so happened, however, that two of these workers were employed in a part of the shed unaffected by the fans, and only one was exposed to their influence. Any attempt to introduce fans into weaving sheds will always be met by a few premature objections of this type, but in most cases the difficulty can be overcome by suitable explanation and persuasion.

During the course of the investigation, mild complaints were sometimes made by one or two weavers (entirely outside the influence of the fans), that the cloth was weaving badly. These weavers, not having fans and being very human, naturally attributed the cause to the only perceptible novelty in the shed. One of the older objectors previously mentioned who worked a considerable distance away from the fans, and was entirely unaffected by the increased air movement they created (as shown by measurements of air movement near her looms), blamed the fans for causing an increase in the number of breakages in the silk threads of her warps She was asked to keep a record of such breakages on the days when the fans were running and also when stopped, but declined to do so. A conversation with the manager disclosed the fact that she was often dissatisfied, so that her attitude towards the fans is easily understood.

The cooling effect produced by the fans was undoubtedly much appreciated. Each of the weavers affected by the increased air movement, when asked if she preferred to have or not to have the fans, invariably replied in their favour, and volunteered such remarks as: "They keep me cooler," "I feel less tired, especially in the afternoons," and "They're fine." On hot days when the fans were stopped, the weavers in question often wanted them to be run. Much to the surprise of the investigator, not a single complaint regarding draughts was heard from these weavers. This was probably due to the fact that the fans were first run on a particularly hot day, when even weavers from distant parts of the shed came and bathed themselves in the breezes they created.

4. General Considerations.

The results obtained in this investigation show that the increased rate of air movement created by the fans had a favourable effect upon the operatives, and was also instrumental in increasing weaving efficiency. It was particularly beneficial on days of high temperature and humidity, and increased the cooling power of the air to such an extent that the operatives were able to work with the same facility as on days of much lower temperature or humidity. The particular arrangement and type of fans adopted in this investigation, although highly satisfactory, may, however, not be the best possible. In the first place, they were effective over a fairly wide area, and included several weavers

within their range. This may be an obstacle to their wider adoption in the industry, since operatives will usually be found who object to the use of fans in any shape or form. Secondly, they require electric power for their operation, and in many sheds this does not exist. Thirdly, the capital cost involved in fitting up a large shed with fans would be considerable.

Because of these considerations, a number of small fans, operated mechanically from the looms, may be found to be desirable. Such fans could be fixed to the looms so as to have a purely local effect over the working area of a single operative. The cost of running would be almost negligible, and the fans could be switched on or off at the discretion of the weaver. The latter point is important, because it eliminates the possibility of individual objections to increased air movement when it is believed to be undesirable. The physiological constitution of some operatives may require the use of fans when others believe them to be unnecessary, consequently individual and localised control of air movement is advisable if irritation and discontent are to be avoided. If, however, larger fans, having a wider range, are preferred, it is useful to know the air velocity necessary to maintain a desirable cooling standard at different temperatures. This has been determined for dry kata cooling rates of 5 and 6, and is shown in Fig. 13.

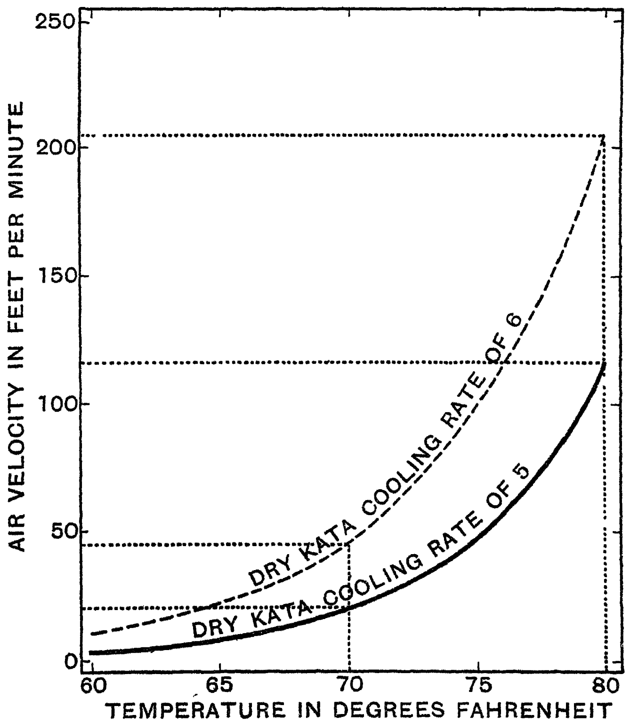

FIG. 13.—Showing air velocities necessary to give dry kata cooling rates of 5 and 6 at different temperatures.

It will be seen that the rate of air movement necessary to give the cooling standards in question progressively increases as the temperature rises. The air velocities required to give cooling rates of 5 and 6 at temperatures of 70° F. and 80° F. are shown by the dotted lines, and are respectively 19·7 and 44·8 ft. per minute for a temperature of 70° F., while for a temperature of 80° F. they become 117 and 205 ft. per minute respectively. In a similar manner the corresponding air velocities at any other temperature can be determined. With such information at the disposal of the management, it should be possible to arrange a system of fans, the speed of which is capable of being automatically controlled according to the temperature of the shed.

The results of this investigation have also shown that, although the number of warp breakages decreases as the temperature or humidity rises, the actual efficiency of production does not follow a similar course. This means that, while the number of loom stoppages may be fewer as the shed atmosphere becomes hotter and more moist, the time taken in attending to these stoppages increases, because of the unfavourable effect of high temperature and humidities upon the weaver. With a temperature of 75° to 80° F., the highest efficiency was obtained when the relative humidity was from 77·5 to 80 per cent., but beyond this degree of saturation the output began to decrease. With a relative humidity of 75 to 80 per cent., the maximum output was obtained when the temperature was from 72·5° to 75° F. Thus, in general, the best conditions for productive efficiency in this shed may be said to be given by a temperature of 72·5° to 75° F. and a relative humidity of 75 to 80 per cent.

From the productive standpoint, it is clear that the management should make every attempt to keep the temperature and humidity within these limits, or whenever this is impossible, to neutralise their effect by means of increased air movement. For the operatives also, the shed conditions would be much improved during the hot summer months.

5. Summary of Conclusions.

The chief points which have emerged from this investigation may be summarised as follows :—

(1) The cooling power of the air and bodily comfort of the operatives were considerably increased by the particular arrangement of fans adopted. The average rate of air movement in a representative position was increased by the fans from 46 to 147 ft. per minute. This produced an increase in the dry kata rate of cooling of 33 per cent., while the evaporative power of the air on moisture at body temperature was increased by 29 per cent. (Page 5.)

(2) Without fans, the cooling power of the air never reached the minimum standard considered necessary for workers engaged in sedentary occupations. With the fans, this minimum was attained whenever the temperature of the shed was below 77·5° F. The air velocity created by the fans made the cooling effect (as shown by the dry kata) at a temperature of 80° F., greater than one of 72·5° F. without fans. (Page 7.)

(3) By running the fans at different speeds according to the atmospheric conditions in the shed, it was possible to maintain a fairly uniform rate of cooling until a temperature approaching 85° F. was reached. Above this temperature more powerful fans would be necessary to preserve the same effect. (Page 9.)

(4) Equally satisfactory results were obtained by the use of small fans which were effective over the area covered by four looms under the control of one weaver. (Page 11.)

(5) The increased air movement produced by the fans had no significant effect upon the number of warp breakages on the looms in their immediate vicinity. (Page 13.)

(6) There were indications that the output on the looms affected by the fans was somewhat higher on the days when the fans were running. The increase was particularly noticeable in spells when the temperature or humidity was unusually high. (Page 15.)

(7) The number of warp breakages decreased as the relative humidity increased. The average percentage decrease for each successive increase of 2·5 per cent. in relative humidity was 9·6. (Page 19.)

(8) The number of warp breakages decreased as the temperature increased. The average percentage decrease for each successive increase of 2·5° F. in temperature was 5·5. In this respect, temperature was less effective than relative humidity. (Page 21.)

(9) The highest output was obtained when the temperature was from 72·5° to 75° F. and the relative humidity 75 to 80 per cent. With higher temperatures and humidities the output decreased. (Page 23.)

APPENDIX I.

Frequency of occurrence of different temperatures and humidities inside the shed and outside in the open air.

The wet and dry bulb temperature readings, together with the corresponding relative humidities, taken at hourly intervals throughout the period of the investigation, have been classified according to differences of 2·5° F. and 2·5 per cent. respectively, and the results are given in Figures A and B.

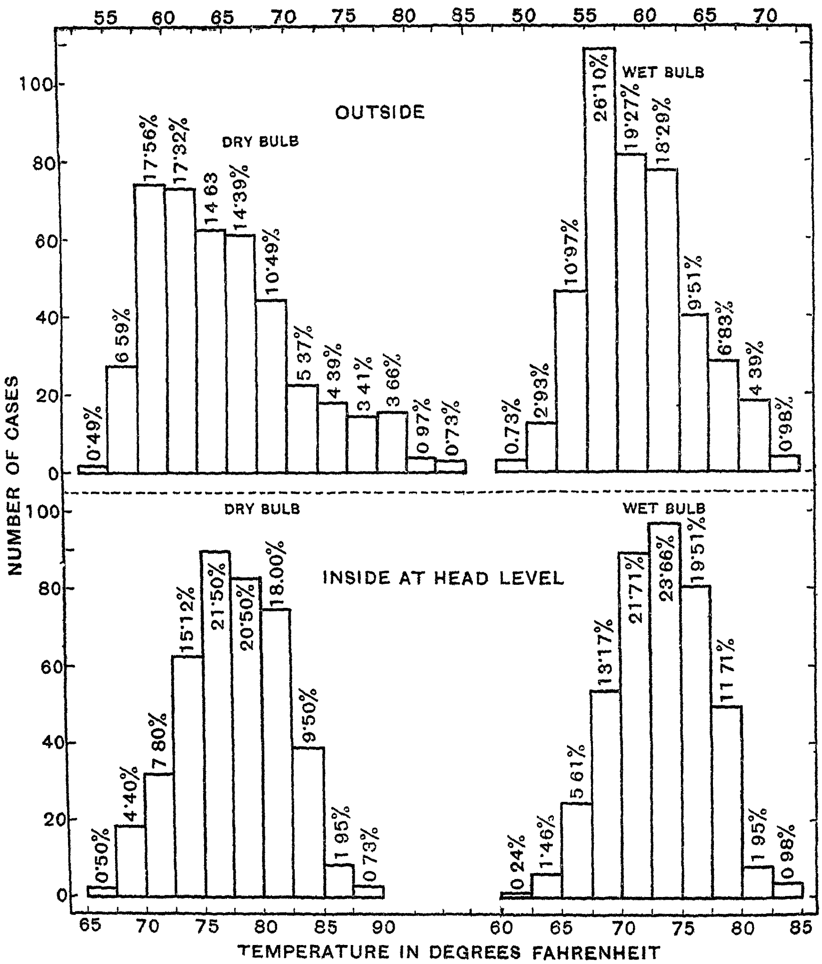

FIG. A.—Showing frequency of occurrence of dry and wet bulb temperatures, inside and outside the shed, throughout the period of the investigation.

These show that the inside dry bulb temperature ranges from 65° to 90° F., but that the majority of readings (75 per cent.) lie between 72·5° and 82·5° F. During the period under consideration, the workers were exposed to a temperature greater than 85° for 2·68 of the total working time, to a temperature exceeding 80° for 30·18 per cent. of the time worked, and to a temperature above 75° for 71·18 per cent. of the total hours worked.

As regards the wet bulb temperatures, these are found to vary from 60·0° to 85°, but the majority (78 per cent.) lie between 67·5° and 77·5°. The amount of time during which the readings exceed 80°, 75°, and 70° is 2·93, 34·15, and 79·52 per cent. of the number of hours worked.[1]

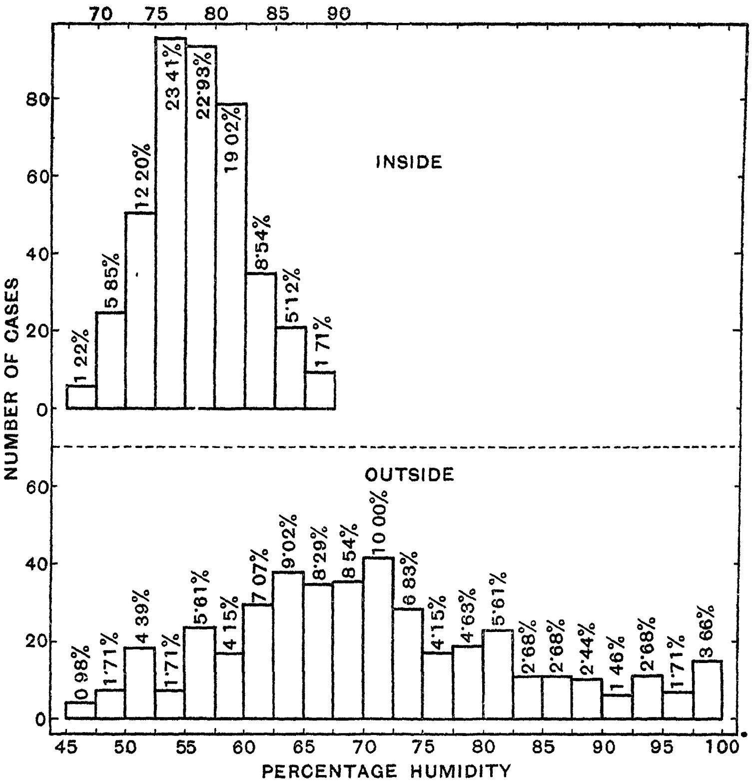

FIG. B.—Showing frequency of occurrence of different relative humidities inside and outside the shed throughout the period of the investigation.

A similar tendency is shown by the results representing relative humidity Here the range is from 67·5 to 90 per cent. with the majority of readings (78 per cent.) lying between 72·5 and 82·5 per cent The number of readings exceeding 85, 80, and 75 per cent of the total hours worked is 6·83, 34·39, and 80·73 per cent. respectively.

The three curves of distribution just considered are similar in shape, and show the extent of variation in temperature and humidity throughout the period under consideration. If the highest weaving efficiency is given by a temperature of 72·5° to 75°, and a relative humidity of 75 to 80 per cent.,[2] then the temperatures prevailing according to the observations

[1] These figures are very similar to those obtained in a previous investigation (1910), when the average of the results recorded in six sheds during the summer months show that the proportion of time spent above a wet-bulb temperature of 80°, 75°, and 70° was 4, 34, and 79 per cent. respectively of the total hours worked (Second Report on Humidity and Ventilation in Cotton Weaving Sheds, Cd. 5566, Table 10).

[2] See, for instance, p. 27 of this report.

will have an adverse effect on output for 85 per cent. of the total time worked; while in the case of relative humidity, unfavourable conditions will exist during 54 per cent. of the working hours. Clearly, if a certain temperature and humidity are more favourable to weaving efficiency than any other temperature and humidity, it follows from the above results that, for approximately 80 per cent.[1] of the total hours worked, the atmospheric conditions in the shed are not such as to ensure maximum efficiency.

The results relating to outside atmospheric conditions were taken at the same time as the inside readings. Both their range and their distribution are appreciably different, and illustrate the extent to which the atmosphere in a humid weaving shed differs from the more normal and natural conditions of the outside air.

APPENDIX II.

Method of correction applied to results in Tables XI and XII

The variations in output on different days of the week, due to the influence of subjective factors, have made it necessary to apply a correction to the results obtained on different days when attempting to determine the effect of temperature and humidity on output (Tables XI and XII)

The average output obtained in corresponding spells in different weeks when the fans were stopped is given in the following table. The results refer to the output obtained from 44 looms and are expressed in picks per hour.

TABLE A.—*Variations in output during a composite week.*

	a.m.	*p m.*	*Day.*
Mon	6753	7199	6978
Tue.	7203	7208	7205
Wed.	7137	7084	7114
Thu.	7218	7042	7133
Fri.	7129	6591	6867
Average	7089	7025	7059

Thus, for example, the average hourly output on a particular Wednesday was 7195, while on a Monday, under similar conditions of temperature and humidity, it was 6926 The average hourly output on all the Wednesdays throughout the period of the investigation was 7114, while the corresponding average for the composite week was 7059 The Wednesday output in question was accordingly multiplied by 7059 and divided by 7114, giving 7140 as the equivalent output apart from the day of the week on which it was obtained. Similarly the Monday output of 6926 was multiplied by 7059 and divided by 6978 (the average hourly output on all the Mondays) giving 7006 as the output expressed in terms of an average week. In this way the effect of variations in the rate of working on different days of the week was eliminated, and the influence of temperature and humidity on output in consequence more clearly shown.

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[1] The most frequently occurring temperatures and humidities are respectively 75° to 77·5° F. and 57 to 77·5 per cent., and each of these represents approximately 20 per cent of the total time worked

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REPORT No. 38.

A Psychological Study of Individual Differences in Accident Rates.

By ERIC FARMER, M.A., and E. G. CHAMBERS, M.A.
Investigators to the Board.

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PREFACE.

It is an acknowledged fact that the physical safeguarding of machinery and plant, however perfect, cannot reduce industrial accidents below a certain limit, and of the remainder, whilst many no doubt are due to pure chance and accordingly unavoidable in the strict sense, others again must be attributed in a greater or less degree to the personal characteristics of the victim himself.

To regard such accidents as inevitable would be unjustified. Much, for instance, can be and has already been achieved by education and propaganda both through official channels and through such organisations as the National Safety First Council and the Safety Committees in many Industrial Establishments. Such efforts, however, have resulted mainly in the discovery of dangerous practices and other risks, and of warnings against them, and the more fundamental question as to whether accidents can be still further reduced through knowledge of the factors underlying personal susceptibility has, until recently, remained largely unexplored.

It is a common practice, for instance, to ascribe the causation of accidents, in the absence of any other obvious explanation, to "carelessness" or "ignorance." These terms, however, would appear to be a very inadequate description of all the actual causes operating, and it is at least probable that they are often wrongly used to cover some inner characteristic (or group of characteristics), the exact nature of which can only be determined by patient study.

The problem to be investigated then resolves itself into two questions :—First, do individuals in fact differ in their individual susceptibility, so that under equal conditions of risk some will incur accidents whilst others will escape, and secondly, if this is so, in what measurable respects do such susceptible individuals differ from their fellows ?

To the former of these questions, an answer is already available. In two of the Board's Reports (the one based on records provided by the Munition Factories during the war,[1] the other on more extensive data specially provided by thirteen large firms in the country[2]), it is shown that the observed distribution of accidents is very different from what would be expected on the theory of pure chance, but is quite consistent with the conception that some individuals, through the possession of certain personal qualities, are unduly liable to accident. This fact indeed corresponds with

[1] GREENWOOD, M. AND WOODS, H M. (1919) :—The Incidence of Industrial Accidents upon individuals with special reference to Multiple Accidents —*Ind. Fat. Res. Bd. Rep. No.* 4.

[2] NEWBOLD, E. M. (1926) :—A contribution to the study of the Human Factor in the Causation of Accidents.—*Ind Fat. Res. Bd. Rep. No.* 34.

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everyday experience, but there remains the further important result also disclosed in these reports, that the specially susceptible individuals constitute a comparatively small group, or (to quote from the summary of one of the reports) that "the average number of accidents in any homogeneous group is much influenced by a comparatively small number of workers."

If then an answer could be obtained to the second of the above questions, the possible practical application of these conclusions is not difficult to see. With the detection and measurement of this abnormal susceptibility by appropriate tests, it might become possible to arrange that unsafe persons were placed in occupations involving the minimum of risk to themselves and others, and through comparatively few such transfers to bring about a substantial diminution in the number of industrial accidents.

The present Report embodies the result of a first step towards the discovery of an answer to this question. Briefly, the method adopted has been to apply selected psychological tests to a large number of workers in different occupations and to compare the results of the tests with the accident records of the subjects examined.

Admittedly, confident conclusions cannot be drawn from the investigation at the present stage, if only for the reason that additional data still remain to be collected before the findings even for these particular subjects can be fully substantiated. Before any scheme of practical value can be formulated, the factors underlying accident proneness must be known and measurable, and to this end much further study on more extensive lines is called for.

In the opinion of the Board, however, the results already obtained may be regarded as distinctly encouraging. The summary table on p. 31 indicates that the majority of tests employed have yielded positive indications, and although the results of most of the tests are not significant in a statistical sense, the consistency with which differentiation by the tests is associated with differentiation by accident rate and the fact that when the results of the significant tests are combined, a still clearer relationship appears between performance in the tests and accident rate justify the hope that research continued on similar lines will eventually lead to conclusions of real industrial importance.

The special thanks of the Board are due to the Admiral Superintendent of H.M. Dockyard, Portsmouth, to the Commandant of the Royal Air Force Establishment, Halton, and to Messrs. James Pascall, Ltd., for the extensive facilities granted by them throughout the present investigation.

November, 1926.

A Psychological Study of Individual Differences in Accident Rates.

By ERIC FARMER, M A , and E. G CHAMBERS, M.A , *Investigators to the Board.*

CONTENTS.

PART I.—GENERAL.

INTRODUCTION.

Within recent years much attention has been paid to the personal factor in accident causation, and in particular to the question whether, given similar conditions of exposure, one individual is more likely than another to incur accidents. That the answer is an affirmative one is the conclusion reached by Greenwood and Woods* and more recently by Newbold,† who, by comparing the accident rates of the same individuals during different periods, were able to show that taking an equal period of equal exposure, accident incidence is not wholly a matter of chance, but depends largely on some quality of special susceptibility inherent in the personality of the victim.

This conclusion is based on statistical reasoning and very little light is thrown on the ultimate causes of the difference in susceptibility, causes which, if known, might eventually enable us to distinguish individuals that are likely to have accidents from those that are not. The present Report describes an attempt to gain knowledge on this subject and to discover something of the personal factors underlying accident susceptibility.

The great difficulty to be met in all investigations of this kind is variation in the exposure to risk on the part of the individuals studied. Since the most obvious explanation of inequality in number of accidents incurred is a corresponding inequality in exposure to risk, it is all the more important not to assume without definite proof that varying individual susceptibility is the cause. In the case of the statistical inquiries, the method adopted was to select only individuals in any group who were employed in manufacturing the same article in the same way, but such equality of exposure was admittedly but a rough approximation, since the conditions of exposure may in practice be so variable that complete uniformity over a long period could not be assumed.

In the present investigation the question of individual susceptibility has been explored in another way. Various psycho-physical tests have been given to groups of factory workers and it has been found that those who did well in certain of them tended to have fewer accidents than those who did badly. On the hypothesis that inequality in accident rate is entirely due to inequality in exposure to risk, we should have to make the assumption that those who did well in the tests were subsequently exposed to less

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* GREENWOOD, M. AND WOODS, H. M. (1919): The Incidence of Industrial Accidents upon individuals with special reference to Multiple Accidents.—*Ind. Fat. Res. Bd. Rep. No.* 4.

† NEWBOLD, E. M. (1926): A Contribution to the Study of the Human Factor in the Causation of Accidents —*Ind. Fat. Res. Bd. Rep. No.* 34.

risk than those who did badly, in spite of the fact that no one who had any connection with the allocation of their tasks had any knowledge whatever of the results of the tests. Such an assumption amounts practically to an impossibility, expecially when the same phenomenon is observed in different groups, and so we are led to the conclusion that inequality in accident rate is, in part at least, determined by the quality or qualities measured by the tests. The operation of this quality (or qualities) can be measured, and the difference between the number of accidents prognosticated by means of the tests and the actual number sustained by the group is a clear indication of how far other factors are operative. This process can be continued until all the measurable factors have been examined and the residue of accidents that still remains must be put down to unknown or unmeasurable factors, one of which may be inequality in exposure to risk.

The fact that one of the factors connected with accident liability has been found to be a peculiarity of the individual allows us to differentiate between "accident proneness" and "accident liability." "Accident proneness" is a narrower term than "accident liability" and means a personal idiosyncrasy predisposing the individual who possesses it in a marked degree to a relatively high accident rate. "Accident liability" includes all the factors determining accident rate: "accident proneness" refers only to those that are personal. We do not know yet whether accident proneness is a general or a specific factor*, but if it should ultimately be found to be a general factor, then an individual working in a dangerous trade with a low degree of accident proneness would have a relatively low accident liability as compared with others engaged in that trade, though it would be greater than that of an individual with an equal degree of accident proneness working in a less dangerous occupation.

Care must be taken not to make accident incidence *per se* a measure of accident proneness, for this is to adopt the position of those who say that accidents are due to carelessness and when asked to define carelessness do so in such a way as to leave little doubt that by carelessness they mean having an undue number of accidents "Accident proneness" implies the possession of those qualities which have been found from independent research to lead to an undue number of accidents. If the term is used in this way, a person can be said to be accident prone without any knowledge of the number of accidents he has sustained, for this statement will merely mean that he is more likely than others in equal conditions of exposure to sustain accidents. Such a knowledge would make it possible to warn certain people against entering dangerous occupations, so that, although they were accident prone in a relatively high degree, they might go through life with very few accidents.

* A general factor is one that is operative in all occupations, a specific factor one that is operative in certain occupations only.

The Definition of an Accident.

An accident for the purposes of this enquiry has been taken to consist in an attendance at the factory surgery for any reason other than sickness or redressing. Accidents not incurred in the factory have not been taken into account, except in the case of two groups of Air Force apprentices who lived in barracks and whose extra-factory injuries were attended to by the official doctor.* No attempt has been made in the body of the report to distinguish between major and minor accidents. The reason for this was that the number of serious accidents is comparatively small so that it would be impossible to get sufficient data to yield reliable results if attention were paid to these alone. Moreover, from a psychological point of view an accident is merely a failure to act correctly in a given situation, and the relative gravity of the result of such a failure must be regarded as irrelevant, except in so far as fear of (or indifference to) the consequences may influence the action leading to an accident.

General Results Obtained.

Application of Tests.

Six hundred and fifty-one subjects were tested, of whom 611 were boy apprentices and 40 were women factory workers.

† The tests used fall into three groups :—

Group I. (*a*) Dotting test.
(*b*) Reaction time test.
(*c*) Pursuit meter test.

It is proposed to call them " aestheto-kinetic co-ordination " tests, because in every case afferent nervous impulses received through the medium of some specific sense organ have to be interpreted by the subject as a sign for varying muscular performances of the hand, arm, or other part of the body. If these tests are to be carried out efficiently the " signs " and the muscular performances to which they are intended to lead must be accurately co-ordinated. This term was invented in order to avoid the use of such terms as " sensori-motor " or " neuro-muscular," which already have well-defined scientific meanings differing from that which we have given to " aestheto-kinetic." Moreover, we are anxious to emphasise the fact that the tests directly measure no more than the ability to perform a specific task, and " aestheto-kinetic," as we have defined it, is a descriptive term applied to a number of tests having a certain aspect in common, and must not be taken to imply a general psycho-physical factor. To argue that a person who does well in these tests must have good " aestheto-kinetic co-ordination " *in general* is to leave the realm of fact for that of inference. Such a step is not only permissible but desirable in scientific research, but it should be recognised as an inference from facts and not in itself a fact.

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* As all the individuals composing the two groups lived much the same life both in and out of the workshops and were attended by the same doctor, there was no reason for excluding their non-industrial accidents. For obvious reasons this could not be done with the civilians examined.

Group II. consisted of,

(*a*) Tests of ocular balance*

(*b*) Tests of tremor.

(*c*) Psycho-galvanic reflex test.

These tests have all been shewn to bear a direct relation to temperamental instability which is probably an important factor in relation to accident liability. The tests of ocular muscle balance are clearly connected in some aspects with what we have called "aestheto-kinetic co-ordination," but they differ in two very important ways. First, they are simple *perceptual tests* rather than tests of motor dexterity and skill; and second, the muscular adjustment involved affects the same sense organ as received the original stimuli. However, there is no genuinely hard and fast line to be drawn between any of the groups of tests, the classification being rather a matter of convenience than of anything else.

Group III consisted of,

(*a*) An intelligence test.

(*b*) The number setting test.

These we have called reasoning tests because rapid and accurate thought is essential in the performance of either test. Reasoning is expressed through a scholastic medium in the intelligence test, and through a mechanical medium in the number setting test.

The dotting, reaction, and pursuit meter tests all had a definite connection with accident liability. They all correlated to a slight but significant degree with each other. They did not correlate with intelligence as measured by the tests used, nor with ocular muscle balance, which there is some reason to suppose is connected with temperamental instability†. The fact that these three tests are united by their intercorrelations and by their relationship to

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* Normally the two eyes are related to each other in position by a muscular mechanism, so that the two visual axes meet at the point of fixation. When the visual axes assume a position relative to each other so that they do not meet at the point of fixation, Strabismus or Squint is said to occur When the deviation of the two axes is obvious the condition is known as Manifest Strabismus, and when the deviation is compensated by continuous muscular action, and only elicited by special tests, the squint is called Latent. If, however, the two eyes are dissociated by presenting to them an object in such a way that binocular fusion is impossible, the eyes take up their position of rest and a latent squint can be detected. Disturbances of ocular muscle balance are spoken of collectively as Heterophoria. If the deviation is a convergence the condition is called Esophoria; if divergence, Exophoria; and if vertical, Hyperphoria.

† Under the term "temperamental instability" are included all those deep-seated factors, whether innate or acquired, which unconsciously affect an individual's nervous and emotional reaction to environment. "Temperamental" should be taken to include "neurological" instability, i.e. nervous instability which is primarily physiological in origin, and "psychological" instability which is primarily emotional in origin; and by using the term we can retain an agnostic position as to whether any particular instability is physiological or psychological In the present state of our knowledge such an agnostic position has much to recommend it.

accidents, and also by their lack of relationship to intelligence and ocular muscle balance, is an indication that they measure some psycho-physical process which they all have in common and which may be called "aestheto-kinetic co-ordination." The fact that their intercorrelations are small shows that this common factor plays a smaller part in the performance of the tests than the factors by which they are differentiated.

The weighted scores of these three tests showed that those who passed them had an average accident rate 48 per cent. less than those who failed. The consistent results obtained from all of the six groups tested indicate that these tests are not likely to yield results markedly more fruitful in future experiments. They will of course have to be tried over a wider field for the sake of confirming the present results, but in order to advance our knowledge of the relationship between accident rate and personal qualities other tests will have to be devised in order to see if their relationship to accident liability is more marked than that of those already used.

There are two ways in which these so-called aestheto-kinetic tests can be developed. One is to devise tests which shall demand not only rapid and accurate reaction, but also careful thought for their performance. A new test called the "number-setting test" was used for this purpose in certain of the groups tested. It correlated significantly though in a low degree with the intelligence test and with the reaction test and in one case with the dotting test, so that there is some reason to suppose that it measures intelligence expressed through a mechanical medium. It did not however show any relationship to accident rate. In view of the fact that intelligence also showed no relation to accident rate, it seems that this line of developing aestheto-kinetic tests is unprofitable from the point of view of accident research.

The other way of developing these tests is to make both the stimulus and response more complicated and to endeavour to devise tests presenting a general stimulus situation rather than a series of stimuli, while making every effort to subordinate the factor of intelligence. The object of such tests would be to measure co-ordination on a higher level and not to measure co-ordination complicated by the factor of reasoning. If such tests can be devised and if the results they yield are as consistent as those already obtained by the so-called aestheto-kinetic tests, then their relation to accident liability can be examined and compared with that of the less complicated tests. It may ultimately be possible to modify present terminology and to speak of "lowly and highly integrated" co-ordination processes, but before doing this the results from the more complicated aestheto-kinetic tests must be awaited.

In one group it was possible to compare the industrial efficiency of the subjects with their performance in the tests. The half of

this group who were selected on account of their industrial inefficiency did worse in all the tests and had a larger number of reported sicknesses and accidents. Before any definite conclusions can be drawn as to the connection between industrial efficiency and accident proneness, other groups will have to be examined in a similar way. If when this has been done the present results are confirmed, then it may ultimately be possible to indicate by means of tests those who, although medically fit, are yet so constituted as to find the strain of modern industry too great and who react against this unfavourable environment by sustaining a relatively high accident and sickness rate and also by industrial inefficiency. Such a conclusion is by no means proved, but the results hitherto obtained are not inconsistent with it.

Changes in conductivity in the direction of lowered resistance (as measured by the psycho-galvanic reflex), excessive tremors, and hyperphoria (deficient ocular muscle balance in the vertical plane) all showed a relationship to accident rate. As all these tests are in some degree connected with temperamental instability they provide an indication that poor co-ordination is not the only psycho-physical factor determining accident proneness.

Relation between Major and Minor Accidents.

Besides the tests given to discover some of the personal factors in accident causation, the relationship between major and minor accidents was examined to see how far the same individual was liable to sustain both types of accidents.

The correlation coefficients between major and minor accidents are for most of the groups examined positively significant ; in some cases they are insignificant, but in no case are they negatively significant Both Greenwood and Woods, and Newbold obtained correlation coefficients between minor accidents in different periods somewhat higher than those found in this inquiry between major and minor accidents.

Three reasons can be put forward to account for the comparatively low correlation coefficients between major and minor accidents, but they are in the nature of conjectures and there is no evidence at present to support them. It is possible that in certain trades major accidents are less under the control of the individual who sustains an injury than minor ones. For example, if scaffolding gives way or machinery breaks down, the cause may be in no way connected with the victims of the accident, who, in the sense defined in this report may be relatively free from accident proneness. Again, the mean of the distribution of major accidents is naturally smaller than that of minor accidents and it may well be that a year—the period over which these records were compared—is insufficient to provide a real basis of comparison. Finally there may be two distinct types of individuals, one which tends

to sustain many small accidents and another which is relatively immune from minor accidents, but is liable to collapse suddenly and so sustain serious injury. It would be unwise at present to assume any of these causes as the main reason for the relatively low correlation co-efficients between major and minor accidents. It may be possible later to throw some light on the matter, but until further data are forthcoming, judgment must be reserved.

Relation between Accidents and Sickness.

Sickness, when measured by time lost owing to absence from work, shows little relationship with accident incidence, and this confirms the results obtained by Newbold. In one group, however, it was possible to measure the relation between sickness reported to the ambulance room and accidents; and here it was found, as already mentioned, that the accident-prone tended to report sick more often than the others. This also agrees with the results obtained by Newbold concerning the relation between reported sickness and accidents.

Possibly this difference in the relationship between accidents and sickness when the latter is differently measured may be explained by some psychological factor which tends to make the accident-prone report sick although organically they are not less healthy than others.

CONCLUSION.

This report is of a preliminary nature and all the conclusions arrived at will have to be substantiated before they can be regarded as reliable, but even these results show that the distribution of accidents is in some degree determined by personal measurable qualities. These qualities appear from the present results to be connected with poor aestheto-kinetic co-ordination on a lowly integrated level and with temperamental instability, and to have no connection with the reasoning processes. Whether it will be possible to discover other personal measurable factors connected with accident liability remains to be seen, but an attempt should certainly be made. The present method of treating the data can be refined as explained in Part II. The reliability of the tests will have to be established and the weights used may have to be modified in the light of further experience. The present results refer only to adolescents and mainly to males; how far they will prove applicable to adults and what sex differences may appear has still to be discovered. To have reached the first stage towards discovering the operation of the personal factor in accident causation is encouraging, although it serves mainly to show how much further research must go before the results obtained can take their proper place in practical life.

PART II.—THE INVESTIGATION.

THE GROUPS TESTED.

Group A were employed in sweet covering. This process was carried out entirely by hand and the exposure to risk of each member was equal.

Group B were employed in packing sweets, and they were exposed to an unequal degree of risk according to whether they packed mainly into tins or bottles. It was impossible to get any reliable measure of this inequality of risk. These two groups were chosen in pairs, each member of a pair being equal in age and experience, but differing in the fact that one member of the pair had had an undue number of accidents whilst the other had had none in the A group, and only a few in group B. The higher accident rate in group B made it impossible to get any workers entirely free from accidents. Both of these groups were tested a second time after the lapse of a year. The original method adopted was to compare the performance in the tests of the accident and non-accident groups. This proved unsatisfactory and so the method described below was employed.

Group C were dockyard apprentices employed as shipwrights, engineers, plumbers, joiners, coppersmiths, and electrical engineers. Group D was another entry of dockyard apprentices employed similarly to group C. Group E were Royal Air Force apprentices employed as carpenters, engine fitters, riggers, motor body builders, and coppersmiths. One-half of the group was composed of those who had failed to pass their final examination and were retained for further training, and the other half were the top boys in the next entry. Group F were Royal Air Force apprentices who had just commenced training and were employed similarly to Group E.

Table I gives particulars of the groups tested showing the numbers, the average age and accident rates with their ranges, and the period of exposure for each group.

TABLE I.—*Details of Groups Tested.*

Group.	No.	Sex.	Age.		Accidents.		Exposure. (Mths.)
			Average.	Range.	Average Rate	Range.	
A ..	17	F	17·1	16–20	1·7	0–10	12
B ..	23	F.	17·6	14–23	6·9	0–31	12
C ..	57	M.	16·9	16–18	0·59	0– 7	24
D ..	100	M.	15·8	15–17	0·33	0– 5	12
E ..	175	M	18·8	17–20	0·64	0–18	36
F ..	279	M	16·1	15–17	0·47	0– 4	9

The product moment method of correlation was not employed on account of the small range of accidents in certain groups. Instead of this the following method was adopted Each group was divided into two sub-groups, i.e., those above and those below the mean in each test (known hereafter as the " better " and " worse " sub-groups). The average accident rate for each sub-group was then found, and expressed as a percentage of the mean for the whole group. In this way all the figures referring to accident rate are made directly comparable, which greatly facilitates the understanding of the results.

In the case of groups A and B, each pair of workers came at the same time of day so that the factor of fatigue should be constant for the accident and non-accident groups in both departments. The accident records of groups C, D, E and F, were not known to the investigators at the time the tests were carried out, so that it was impossible to arrange that accident and non-accident subjects should come at the same time of day. The time at which each person was tested was noted and subsequently a diurnal curve of performance in each test was made. The accident rates of those who came at each hour were plotted alongside and the two curves compared. The curves of performance conformed to the usual shape of such curves, but that of the accident rate was practically a straight line. This shows that the tendency for those with a high accident rate to do worse in the tests than the others is not due to the time of day at which they were tested, the accident rate of those tested each hour being approximately equal. In presenting the results of these experiments which deal only with group differences, therefore, no allowance has been made for the time of day at which the testing took place, because it did not affect the group results on account of the random distribution of the accident rate. If similar tests were used for determining the careers of individuals allowance would have to be made for the effect of time of testing. This could only be done when norms of performance have been established, and the present data are not sufficient to warrant any such attempt being made.

The accident records of group A, B and C, were taken from periods both previous and subsequent to the time at which the tests were made. The accidents of groups D and F occurred subsequently and those of group E previously to the giving of the tests. The relation between the tests and the previous and subsequent accidents has been examined separately in groups A, B, and C, but as they showed no difference, the two periods have been combined in this report. The fact that the tests show the same relation to accidents that occur after the time of testing is sufficient to indicate that the relationship is not caused as a result of the accidents but is due to some quality possessed by the individual both before and after sustaining an accident.*

* *Cf.* Greenwood and Woods, op. cit., p. 9.

The tests were arranged with a view to measuring different levels of mental life, in order to see which level had the closest relationship with accident liability. Reaction time tests, the dotting test, and the pursuit meter were used for measuring aestheto-kinetic co-ordination. An intelligence test and a new test which has been called the number-setting test were used for measuring intelligence as expressed in a scholastic and a mechanical way respectively. The psycho-galvanic reflex, the balance test, together with an examination of the subjects' tremors, were used for determining temperamental stability, and tests were also given for ocular muscle balance. It was impossible for various reasons to give all these tests to every group, and as the enquiry continued, tests which had yielded no positive results were dropped and others substituted. No tests for special abilities were given. These were deliberately omitted so as not to make the field of enquiry too broad, as it was considered better to proceed along narrow lines, but any examination of the factors composing accident proneness must be considered incomplete without an examination of the special abilities making adaptation to specific occupations more easy for some than for others.

Results of Tests Applied.

Reaction Time Tests.

The apparatus used in testing groups A and B on the first occasion was one kindly lent by the Cambridge Psychological Laboratory. It was a choice reaction apparatus with five stimuli and the reaction times were recorded by means of an electrically controlled stop watch The apparatus used in all the subsequent tests was one designed by Dr. E. Schuster and had six stimuli, the reaction time being recorded automatically on a roll of paper It was also possible to use this apparatus for simple reactions; the position of the response keys could be changed and their distinguishing marks covered up, which made it possible to measure the effect of changing a position association and also of substituting a position association depending entirely on visual memory and not upon sight This apparatus greatly facilitated the testing, because the automatic method of recording saved time and also obviated errors that might arise on account of the operator failing to read the stop watch accurately.

In order to see how far different degrees of complexity in reaction were related to accident liability, the following series of reaction experiments was given :—

(1) *Simple reactions.*—The subject merely had to take his finger off a button, kept depressed until the stimulus was perceived.

(2) *Simple co-ordination.*—The subject had to move his finger from a given spot to the response key as soon as the stimulus was perceived.

(3) *Choice reaction.*—A series of experiments with differing degrees of choice, in which the subject had to move his finger from a given spot to the proper response key on perceiving the stimulus. The response keys were equidistant from the starting-point so that the same amount of movement was involved in each response. The choice varied between two and six stimuli.

(4) *Complications.*—The subject was required to respond not to the proper response key of the stimulus, but to another indicated on a chart placed immediately before him.

(5) *Cover up.*—The distinguishing marks of the response keys were covered up and the subject had to respond to the correct key with only his memory to aid him.

(6) *Distraction.*—Sudden loud noises were made just behind the subject during the test.

(7) *Changed Position.*—The position of the response keys was changed, so that a new position association had to be formed by the subject. (4), (5), (6), and (7) involved choice between six stimuli.

(8) *Selective.*—The subject was required to respond to a given stimulus, only when it was preceded or followed by another specified stimulus.

(9) *Dilemma test.*—The subject was required to respond only to a specified stimulus, although many other successive stimuli were also given to which no response was to be made.

The method of presenting the data is to express each individual's accident rate as a percentage of the mean rate in his own group and then to show the average percentage accident rate of those above and below the mean in each of the tests. This method has been adopted throughout so as to facilitate comparison both between tests and also between groups.

The results of the various reaction time experiments are given in Table II, and their intercorrelations in Table III.

TABLE II.—*Average Percentage Accident Rates of those better and worse than the Averages in the Reaction Tests.*

Group.	Simple Reaction (20)*		Simple Co-ordination. (12)		Choice between										Complications. (20)		Cover-up (10)		Distraction (10)		Selective (20)		Dilemma (15)		Change of Position (10)		1st Time of Testing (5 stimuli) (35)	
					2 Stimuli (5)		3 Stimuli (5)		4 Stimuli (5)		5 Stimuli (5)		6 Stimuli (30)															
	B	W.	B.	W	B	W	B	W	B	W.	B	W	B.	W	B	W	B	W	B.	W	B	W	B	W.	B	W	B	W
A	112	76	65	129	88	129	82	135	106	94	112	94	106	94	112	94	100	100	94	106	—	—	100	100	76	135	59	159
B	106	91	81	116	78	141	96	103	123	80	75	116	75	123	97	104	99	101	87	125	—	—	75	119	78	123	86	125
C	—	—	—	—	—	—	—	—	—	—	—	—	100	100	68	125	—	—	—	—	71	137	—	—	—	—	—	—
D	—	—	—	—	—	—	—	—	—	—	—	—	64	145	76	124	—	—	—	—	—	—	—	—	—	—	—	—
E	—	—	—	—	—	—	—	—	—	—	—	—	92	108	—	—	—	—	—	—	—	—	—	—	—	—	—	—
F	—	—	—	—	—	—	—	—	—	—	—	—	79	126	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Weighted Averages	109	85	74	122	82	136	89	113	115	85	92	107	83	120	79	119	99	101	89	115	71	137	87	112	77	128	75	140
Differences	−24		+48		+54		+24		−30		+15		+37		+40		+ 2		+26		+66		+25		+51		+65	
Probable Errors	27 3		26 5		27 9		26 4		26 4		28 8		10 9		23 2		26 5		27 3		57 0		26 5		26 5		27 2	

* Figures in brackets denote the number of stimuli given

TABLE III.—*Intercorrelations, between the Reaction Tests for Groups A and B.*

—		Simple Co-ordination.	2 Stimuli.	3 Stimuli	4 Stimuli	5 Stimuli	6 Stimuli	Distraction	Cover up	Complications.	Changed Position.	Simple Reaction.	Dilemma.	1st Time of Testing.
Simple Co-ordination	A	—	0·45	**0·59**	0·45	0·49	0·20	0·30	0·04	0·30	0·29	0·17	—0·03	0·25
	B	—	**0·44**	**0·70**	**0·83**	**0·79**	**0·70**	**0·66**	**0·56**	**0·49**	**0·49**	**0·47**	0·27	**0·44**
2 Stimuli ..	A	0·45	—	**0·59**	**0·64**	0·37	**0·78**	**0·76**	**0·54**	**0·52**	**0·60**	0·01	—0·36	**0·58**
	B	**0·44**	—	**0·54**	**0·50**	0·43	**0·67**	0·39	0·43	**0·46**	**0·48**	0·12	0·35	0·12
3 Stimuli ..	A	**0·59**	**0·59**	—	0·41	**0·75**	**0·74**	**0·75**	0·27	**0·47**	**0·56**	0·30	—0·17	0·19
	B	**0·70**	**0·54**	—	**0·76**	**0·72**	**0·67**	**0·48**	**0·52**	**0·59**	**0·63**	0·41	0·33	0·43
4 Stimuli ..	A	0·45	**0·64**	0·41	—	0·30	**0·74**	**0·56**	0·46	0·41	**0·61**	—0·06	—0·49	**0·56**
	B	**0·83**	**0·50**	**0·76**	—	**0·86**	**0·67**	**0·51**	**0·61**	**0·62**	**0·62**	0·29	0·13	**0·44**
5 Stimuli ..	A	0·49	0·37	**0·75**	0·30	—	**0·59**	**0·65**	0·34	0·43	0·35	0·39	0·09	0·24
	B	**0·79**	0·43	**0·72**	**0·86**	—	**0·74**	**0·56**	**0·70**	**0·60**	**0·53**	0·33	0·26	0·33
6 Stimuli ..	A	0·20	**0·78**	**0·74**	**0·74**	**0·59**	—	**0·87**	**0·66**	**0·51**	**0·61**	0·11	—0·29	**0·69**
	B	**0·70**	**0·67**	**0·67**	**0·67**	**0·74**	—	**0·46**	**0·78**	**0·73**	**0·53**	0·30	0·20	0·29
Distraction ..	A	0·30	**0·76**	**0·75**	**0·56**	**0·65**	**0·87**	—	**0·53**	**0·61**	0·48	0·10	0·08	**0·66**
	B	**0·66**	0·39	**0·48**	**0·51**	**0·56**	**0·46**	—	0·41	**0·49**	**0·44**	**0·47**	0·42	0·41
Cover-up ..	A	0·04	**0·54**	0·27	0·46	0·34	**0·66**	**0·53**	—	0·30	0·22	0·07	—0·32	0·43
	B	**0·56**	0·43	**0·52**	**0·61**	**0·70**	**0·78**	0·41	—	**0·61**	**0·54**	0·16	0·03	0·37
Complications	A	0·30	**0·52**	0·47	0·41	0·43	**0·51**	**0·61**	0·30	—	**0·52**	0·40	0·05	**0·55**
	B	**0·49**	**0·46**	**0·59**	**0·62**	**0·60**	**0·73**	**0·49**	**0·61**	—	**0·68**	0·43	0·34	0·27
Changed Position	A	0·29	**0·60**	**0·56**	**0·61**	0·35	**0·61**	0·48	0·22	**0·52**	—	0·37	—0·18	**0·58**
	B	**0·49**	**0·48**	**0·63**	**0·62**	**0·53**	**0·53**	**0·44**	**0·54**	**0·68**	—	**0·50**	0·23	0·35
Simple Reaction	A	0·17	0·01	0·30	—0·06	0·39	0·11	0·10	0·07	0·40	0·37	—	**0·52**	0·13
	B	**0·47**	0·12	0·41	0·29	0·33	0·30	**0·47**	0·16	0·43	**0·50**	—	0·41	**0·48**
Dilemma	A	—0·03	—0·36	—0·17	—0·49	0·09	—0·29	0·08	—0·32	0·05	—0·18	**0·52**	—	0·08
	B	0·27	0·35	0·33	0·13	0·29	0·20	0·42	0·03	0·34	0·23	0·41	—	0·25
1st Time of Testing	A	0·25	**0·58**	0·19	**0·56**	0·24	**0·69**	**0·66**	0·43	**0·55**	**0·58**	0·13	0·08	—
	B	**0·44**	0·12	0·43	**0·44**	0·33	0·29	0·41	0·37	0·27	0·35	**0·48**	0·25	—

To avoid undue complication, the probable errors have been omitted from this and the subsequent tables of intercorrelations The correlation coefficients which are more than two-and-a-half times their probable errors, and so may be counted as significant, are printed in clarendon type

Table II shows that the percentage accident rate in all groups of those better than the mean in the time taken to respond to the stimulus is lower than that of those worse than the mean, except in nine cases out of thirty-three, all of which occur in groups A and B. These groups are the least reliable not only on account of the fewness of their numbers but also because in each there was one worker with an outstanding number of accidents (10 in group A, the group average being 1·7 ; 31 in group B, the group average being 6·9). The half in which either of these workers appeared in any test always had a higher accident rate than the other half. In the other groups there were no outstanding cases of this kind and, if there had been, the larger numbers in the groups would have prevented them playing too dominant a part in the final results.

The weighted averages* in Table II have been given so as to allow each group to have its exact numerical weight in the average and are a more accurate measure of the significance of the tests than unweighted averages would be. In choice reaction, when six stimuli were used, the difference between the weighted averages is more than two and a half times its probable error. The other differences are not significant, but this lack of significance is probably due to the smallness of the numbers in the groups tested and also to the fewness of the stimuli given. The complicated nature of these tests made it impracticable to give a large number of stimuli, and during the course of the inquiry it became plain that the very large variation occurring in the reaction times to these complicated tests made any average derived from a reasonable number of stimuli extremely unreliable.

From the intercorrelations given in Table III, it will be seen that reaction time experiments tend to correlate both highly and significantly, the average correlation being ·442. For this reason all the various modifications of reaction time experiments were discontinued and the ordinary choice reaction between six stimuli was alone retained as being the most representative of them all. The various modifications introduced did not yield better results than ordinary choice reaction, so that it would seem that the factor connecting a high accident rate with slow reaction was the factor all the reaction tests had in common and not the one by which they were differentiated.

Mistakes.—The number of mistakes made in choice reaction complication, and the selective tests, were scored and the average percentage accident rates of those above and below the mean

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* The formula for the weighted average is $M = \frac{\Sigma(mn)}{N}$;

where m = average of a group,
n = number in that group,
N = total number of all groups.

are given in Table IV. Although on the whole those who made most mistakes tended to have most accidents, yet the results are not consistent and the final weighted average shows such a small difference between those above and below the mean that this method of scoring reaction tests was abandoned.

TABLE IV.—*Accident Rate expressed as a Percentage of the Mean of those better and worse than the Average in Mistakes made in* (1) *Choice Reaction and Complications and* (2) *Selective Reaction Tests*

Group.	Choice Reaction and Complications.		Selective Reaction Tests	
	Better in Test.	Worse in Test.	Better in Test	Worse in Test.
A	46	162	—	—
B	92	106	—	—
C	115	78	85	115
D	97	103	—	—
E	108	87	—	—
F	83	113	—	—
Weighted Averages.	**94**	**102**	**85**	**115**
Difference ..	+8		+30	
P.E. of Diff. ..	11·3		56·4	

Variation in Reaction Time.—The variation of each individual tested in time of response in choice reaction was measured by means of the standard deviation of his reaction times. The results are given in Table V. The weighted average shows that those less variable than the average tend to have fewer accidents than those who are more variable, but the groups are not consistent and the difference between the weighted averages is not significant.

TABLE V.—*Accident Rate expressed as a Percentage of the Mean of those less variable and more variable than the Average in Choice Reaction*

Group.	*Better in Test.*	*Worse in Test.*
A	81	125
B	100	100
C	125	76
D	76	133
E	111	86
F	79	126
Weighted Averages ..	**92**	**111**
Difference	+19	
Probable Error of Difference	11·0	

The correlations between variability and reaction time are given in Table VI and the high and significant correlations show

that those who have long reaction times tend also to be more variable. Variability is therefore not included in the final score, attention being paid only to length of reaction.

TABLE VI.—*Correlations of Reaction Time with Variations in Reaction Time.*

Group.	*Correlation.*
A	·78 ± ·064
B	·03 ± ·141
C	·70 ± ·046
D	·66 ± ·038
E	·47 ± ·040
F	·51 ± ·030

Dotting Test.

The apparatus used for groups A, B, C, and D, was Schuster's modification of the McDougall machine. The subject was required to dot a series of small circles passing in front of him at an increasing speed. The same machine was used for groups E and F, but Dr. Schuster altered the apparatus, so that although the test remained the same for the subject, the scoring was made automatic by the introduction of an electrically controlled Veeder counter. This was a great improvement for not only did it save time, it also obviated any personal factor in the scoring.*

The results from the dotting tests are given in Table VII, in which it will be seen that those who do better than the average have a lower accident rate in every group than those who are worse than the average. The difference of the weighted averages is just over four times its probable error, so that it may be regarded as fully significant. The dotting test is the easiest and quickest of all the tests to give, and can be given by any intelligent person without special psychological training. For these reasons it is admirably fitted to become a practical test, and the fact that it serves to differentiate the accident-prone is very fortunate.

Table VII.—*Accident Rate expressed as a Percentage of the mean of those better and worse than the Average in the Dotting Test.*

Group	*Better in Test.*	*Worse in Test.*
A	41	153
B	90	112
C	71	122
D	76	124
E	79	123
F	72	126
Weighted Averages	**74**	**125**
Difference	+51	
Probable Error of Difference	12·0	

* With the original method of scoring it was sometimes difficult to be certain whether a dot was in a circle or only on the circumference, but with the new method no such confusion could arise, because if the stylo is not placed in the circle, electrical contact is not made and nothing is scored.

Pursuit Meter.

A pursuit meter which gave a graphic record of the subject's ability to follow a moving pointer with a regular or irregular rhythm was constructed by Dr. E. Schuster. This apparatus was used for groups C and D. It was found, however, that the scoring entailed a great deal of labour and also involved a certain amount of personal judgment. The original idea of making a graphic record was to see if qualitative as well as quantitative differences could be discovered between individuals. This, however, proved to be impossible if a high standard of accuracy was to be maintained, so that finally only the quantitative method of scoring was used.

For groups E and F a new pursuit meter, also constructed by Dr. Schuster, which gave an automatic quantitative record of the subject's ability to follow a moving pointer, was used. The movements of the pointer could be made to follow four different patterns and the final score was the total of the scores for each pattern.

TABLE VIII.—*Accident Rate expressed as a Percentage of the Mean of those better and worse than the Average in the Pursuit Meter Test.*

Group.	*Better in Test*		*Worse in Test.*
C	80		125
D	76		124
E	98		100
F	92		113
Weighted Averages	**90**		**112**
Difference		+22	
Probable Error of Difference		11·6	

The results of this test are given in Table VIII. Those better than the average have in each group a lower accident rate than those who are worse than the average. The difference of their weighted averages, however, is only twice its probable error so that it is not quite significant. Groups C and D were tested with the original apparatus, giving a graphic record. As has already been pointed out, the method of scoring these records involved a personal factor of error in reading the points on a very fine scale, and since the differences in these two groups are larger than those in groups E and F, it might appear that the judgment of the scorer had been unconsciously biassed. This, however, was impossible, for the investigator who marked the records did not know the accident rates of the subjects at the time the marking took place as they were collected later. There seems no obvious explanation to offer for the fact that the results

obtained from groups C and D are more positive than those from groups E and F. The investigators are convinced by experience with both pieces of apparatus that the one used for groups E and F is more accurate ; and the numbers in these groups are larger and therefore the results are likely to be more reliable. The test, as far as the subject was concerned, was essentially the same in both cases, the only difference being that the apparatus used for groups E and F permitted of four different patterns instead of two, and the patterns were certainly more complicated than those of the original apparatus. It may be that by making the test longer and more difficult a fatigue element was introduced which tended to mask the relation between the test and accident proneness. There is no means of measuring this, so that the suggestion is merely a conjecture without any experimental evidence to support it. It is not always wise to abandon a test that at first does not yield significant results. If the results are consistent it often happens that with further observations real significance is obtained. For this reason the pursuit meter records are used in the final combined scores and further research will be made with it.

Ocular Muscle Balance.

The ocular muscle balance of groups A, B, C, and D was examined by means of the red-green test used by Dr. C. Clements in testing candidates for the Royal Air Force. The results were shown to Dr. Clements and his criticism and help were greatly appreciated by the investigators. This test consists of placing red and green glasses before the subject's eyes and then presenting a streak of light, half of which is green and half red. The images in each eye are thus made disparate and it is easy to measure esophoria and exophoria when the streak of light is presented vertically, and hyperphoria when it is presented horizontally. Tendencies towards alternation and neglect were also noted.

Groups C and D had all passed a vision test of 6/12 with or without glasses, but groups A and B had passed no such test. This probably accounts for the greater incidence of ocular muscle balance defects in these two groups.

The results are given in Table IX. In all the groups tested, those with a hyperphoric tendency have a higher percentage accident rate than those who are free from this defect. The weighted averages show a difference which is just three short of being two-and-a-half times its probable error, so that we may regard it as practically significant. There are far fewer observations for this test than for those previously described and it seems probable that with more observations a difference more than two-and-a-half times its probable error would be obtained. The percentage difference in accident rate between those with and those without eso-exophoria and neglect and alternation are inconsistent, and in the larger and more reliable groups (C and

D), those having these defects have a lower accident rate than those who are free from them. There is, however, some doubt as to the reliability of the records of neglect and alternation, because it is difficult in certain cases to be sure from the subject's description whether he is suffering from a real defect or merely from a failure to describe what he sees.

TABLE IX.—*Average Accident Rate expressed as a Percentage of the Mean of those with and without various Defects in Ocular Muscle Balance.*

Group	Subjects	Hyperphoria		Eso-exophoria		Alternation and Neglect	
		With	Without	With.	Without	With	Without
A	17	165^{10}	8	265^{4}	50	171^{8}	39
B .. .	23	106^{15}	94	110^{9}	94	184^{7}	64
C	57	119^{23}	86	69^{15}	107	59^{10}	108
D	100	124^{55}	61	79^{23}	106	91^{20}	103
Weighted Averages	(197)	**124^{103}**	**69**	**96^{51}**	**100**	**113^{15}**	**97**
Differences ..	—	$+55^{1}$		-4		$+16$	
P.E of Diff.	—	23·2		26·2		24·6	

The small figures indicate the number of subjects having the defect.

Esophoric and exophoric tendencies were found in practically all the subjects and for this reason no notice was taken of the defect unless the disparate images were more than an inch apart. Hyperphoria is rarer and was considered a graver defect than heterophoria, because in order to adjust divergence in the visual images in the vertical plane muscles are brought into play which are not so constantly used as those employed for adjusting divergences in the horizontal plane. For this reason any tendency, however slight, towards hyperphoria was counted as a defect.

Table X gives the biserial correlation coefficients between hyperphoria and the aestheto-kinetic tests, and it will be seen that they are on the whole negative and insignificant. This gives an additional value to the ocular balance test, for it presumably measures a quality connected with accident proneness which is not measured by the other tests.

TABLE X—*Biserial correlations between Hyperphoria and the Aestheto-kinetic Tests.*

Group.	Correlations between Hyperphoria and		
	Reaction.	Dotting	Pursuit Meter.
A	—·326 ± ·146	—·006 ± ·164	—
B	—·078 ± ·140	·191 ± ·136	—
C .. .	—·176 ± ·087	·040 ± ·088	·242 ± ·084
D	—·132 ± ·066	·125 ± ·066	—·087 ± ·066

*To interpret the sign of the correlation coefficients the relation should be looked on as one between ocular defect and badness in the performance of the tests, i e., a positive sign denotes that hyperphoria is associated with badness in the tests, and vice versa.

Intelligence Test.

Test No. 33 of the National Institute of Industrial Psychology was given to groups E and F, but intelligence as measured by this test (Table XI) was found to have no connection with accident liability.

TABLE XI.—*Average Accident Rate expressed as a Percentage of the Mean of those better and worse than the Average in the Intelligence Test.*

Group.	*Better in Test*	*Worse in Test.*
E	97	103
F	104	98
Weighted Averages ..	**101**	**100**
Difference	— 1	

Manson* found a correlation of —·32 between self-estimated caution and the percentage of errors in an intelligence test. In order to see, therefore, if lack of caution as measured by number of errors had any relation to accident liability, the errors were scored separately in the intelligence test. The results, however, were both inconsistent and insignificant as can be seen in Table XII. Although an intelligence test was only given to two groups, yet they are the largest and most reliable of all the groups, and the negative results obtained indicate that accident proneness is not influenced by differences in intelligence as measured by the test used.

* MANSON, GRACE E (1925); Personality Differences in Intelligence Tests—*J. App Psychol* **9.3** (pp. 2302–56).

TABLE XII.—*Average Accident Rate expressed as a Percentage of the Mean of those better and worse than the Average in the Number of Mistakes in the Intelligence Test.*

Group.	Better in Test.		Worse in Test.
E	105		92
F	85		126
Weighted Averages ..	**93**		**113**
Difference		+20	
Probable Error of Difference		12·3	

Number-setting Test.

A new test which is fully described on p. 40 was devised by one of the investigators and constructed by Dr. Schuster. It consisted of an apparatus operated by two sets of levers arranged in pairs. One of each pair of levers, when pushed forward, caused a certain combination of numbers to appear, and the other lever, when pushed forward, caused it to disappear The subject was required to get certain combinations which required the operation of at least three levers. The method of scoring was by the average time taken to do each of the problems. The results are shown in Table XIII. In both groups those who are above the average in the test have a higher accident rate than those below; the difference of the weighted averages, however, is not significant. The test was designed with a view to measuring intelligence expressed through a mechanical medium rather than a scholastic one, but as this is the first time that it has been used, very little can be said about what it measures, but it correlates significantly in both groups with intelligence and choice reaction, and in one case with dotting (see Table XVII), so that it seems to be connected both with reasoning and manual dexterity.

TABLE XIII.—*Average Accident Rate expressed as a Percentage of the Mean of those better and worse than the Average in the Number-setting Test.*

Group.	Better in Test.		Worse in Test.
E	106		92
F	102		98
Weighted Averages ..	**103**		**95**
Difference		— 8	
Probable Error of Difference		12·2	

During the giving of this test an attempt was made to judge the mental characteristics of the subject by his demeanour. A distinction was made between those who thought out the problem in their heads and those who trusted almost entirely to trial and error. Another distinction was made between those who appeared to be nervous and those who did not, and also between the cautious and the careless. These records have been carefully analysed in many ways but no evidence of a reliable kind that any of these character traits are connected with accident proneness is forthcoming. These negative results may be due to the faulty judgment of the investigator, or it may be that the character traits were on the whole correctly judged and that they have no real relation to accident liability. The investigator who gave the other tests made an independent assessment of character traits and these two assessments on the whole were in agreement. The usual way of judging the reliability of character assessments is to correlate them with other independent assessments, but such correlations only measure the degree in which each assessor has been impressed similarly. It tells us nothing about the real ability of one person to judge another's character, nor the relationship in which any characteristic stands to an objective measure such as occupational success or liability to accidents. The whole problem of character assessment bristles with difficulties and it is suggested that the only way to proceed if this psychological method is to be made truly scientific is always to measure the character assessments with objective facts, and to report the failures of the method as well as its successes.

Tremor.

Groups A, B, and F, were examined for hand, eye, or tongue tremors. No connection was found in any of the groups between tremors and accident rate except when the tremor was excessive. Sixteen subjects in group F had excessive tremor and their percentage accident rate, as may be seen in Table XIV, was 213, as compared with 94 for the rest of the group, a difference of 119, which is significant. Although the difference is shown to be significant by the method used, yet with such small numbers the test for reliability is only approximate. Only one case of excessive tremor was found in groups A and B and this worker had sustained no accidents. The tremor test is simple and quick to give, and although the incidence of excessive tremor is small, yet if further research yields similar results to those obtained from group F, it may ultimately become a useful confirmatory test.

TABLE XIV.—*Average Accident Rate expressed as a Percentage of the Mean of the Group of those with different degrees of Tremor. (Group F.)*

	Subjects	*Accident Rate.*
No tremor	102	98
Slight tremor	39	81
Tremor	53	96
Marked tremor	16	213
	With marked tremor	*Without marked tremor.*
Weighted averages	**213**	**94**
Difference	+119*	

* As there are only 16 with marked tremors the significance of the difference is worked out by means of the tables given in Biometrika XI, pp. 416–417 The expectation that we should get the above difference is 3 in 1,000, hence the difference can be taken as significant.

Psycho-galvanic Reflex.

During the tests each subject in groups A and B was attached to a galvanometer kindly lent by Dr. E. Prideaux, and the changes in conductivity taking place during the period were photographically recorded. There are so many interfering factors entering into the psycho-galvanic reflex that it is difficult to give a proper interpretation of the phenomenon. Some of the factors affecting it we have discussed elsewhere* and it is not proposed to enter into the discussion again in this report. For the present purpose it is sufficient to say that when an electric current is passed through the body, changes in conductivity take place which can be measured by the deflections of a galvanometer placed in the circuit. Many experiments have been carried out, the results of which show that changes in the direction of lowered resistance are connected with emotional states, but there are so many physical and physiological factors which may also have the effect of lowering the resistance and whose operation cannot yet be definitely determined, that it is impossible to be sure in any particular case how far a change of resistance is due to psychological causes and how far to others. The experiments already done, however, allow us to say that on the whole those who manifest a large number of changes in resistance are likely to be more emotionally sensitive and temperamentally unstable than those who do not manifest the same phenomenon.

* FARMER, E., AND CHAMBERS, E. G. (1925). Concerning the use of the Psycho-galvanic Reflex in Psychological Experiments.—*Brit. J. Psychol.* **15.3.**

In Table XV it will be seen that those who have a large number of changes in conductivity in the direction of lowered resistance, and are therefore presumably more emotionally and nervously sensitive than those who have a smaller number of such changes, have in both groups a higher accident rate, and the difference of the weighted averages is just two-and-a-half times its probable error.

TABLE XV.—*Average Accident Rate expressed as a Percentage of the Mean of the Group of those above and below the mean in the number of changes in conductivity towards lowered resistance in the Psycho-galvanic Reflex Test.*

Group.	*Above.*		*Below.*
A	36		159
B	90		116
Weighted averages	70		137
Difference		+67	
P E of Difference		26·8	

These results agree with those obtained by examining the tremors of group F (Table XIV), for a well-marked tremor is another sign of temperamental instability, and although the data are not sufficiently definite to prove that the temperamentally unstable are more likely to sustain accidents than others, yet they are not inconsistent with that hypothesis and are sufficient to warrant further attempts to find out the connection between accident proneness and temperamental instability.

Other Tests.

The pulse rates of groups A and B were taken. They were also required to balance a metal rod on a board at arm's length in order to test steadiness, and enquiries were made as to the distance they had to come to work each morning and the means employed, to see if the fatigue caused by long journeys had any effect on accident rate. No reliable data were obtained from any of these tests, and they were not continued with the other groups.

RELATION BETWEEN AGE, ACCIDENT RATE AND PERFORMANCE IN THE TESTS.

The accident rate and the performances in the Reaction, Dotting and Pursuit Meter tests for each age expressed as percentages of the means of the groups are given in Table XVI. The results for each age are so irregular as to make it impossible to see any connection between them. This irregularity is probably due to the fewness of observations and the small range

of the ages, and cannot be taken as proving that no connection exists. It suffices, however, to show that the connection between the tests and accident rate for these groups is not due to the operation of the age factor.

TABLE XVI.—*Average Accident Rate and Average Score in certain Test Performances expressed as a Percentage of the Means of the Groups for Each Age.*

Age.	Number.	Accident Rate	Test Performances.		
			Reaction Time.	Dotting Test.	Pursuit Meter.
15	165	98	102	98	101
16	200	102	99	100	100
17	73	97	99	104	98
18	115	103	99	101	101
19	48	104	100	102	98

INTERCORRELATION BETWEEN THE TESTS.

The intercorrelation coefficients between the tests are given in Table XVII. The aestheto-kinetic tests (Dotting, Reaction, and Pursuit Meter), on the whole, correlate significantly among themselves, although the coefficients are not large; intelligence correlates significantly and positively only with Number Setting, whilst the latter also correlates significantly with Reaction and in one case with Dotting. From this it may be inferred that Dotting, Reaction, and Pursuit Meter have an element in common, although the lowness of their correlation coefficients shows that the factors which differentiate them are more marked than those which differentiate intelligence tests. The smallness of the correlation coefficients between the aestheto-kinetic tests is probably to some extent accounted for by the fact that they measure aestheto-kinetic co-ordination at a low level. Since higher intercorrelations have been found for more highly integrated tests, it seems that the lower we get in the aestheto-kinetic system the more highly differentiated become the processes. The higher co-ordinating mechanisms, which are the latest biologically, are those which tend to be common to all forms of movement in the same subject, so that tests measuring their operation would naturally yield higher correlation coefficients. These higher mechanisms are the first to be affected by strain, and when satisfactory tests have been found for measuring their operation, a closer connection may be discovered between them and accident rate than that revealed by the use of the present tests.

TABLE XVII.—*Intercorrelations between the Tests for all Groups.*

—	Dotting						Choice Reaction						Pursuit Meter				Intelligence		Number Setting		Ocular Muscle Balance.			
—	A	B.	C	D	E	F	A	B	C	D.	E	F	C	D	E	F	E	F	E	F.	A	B	C.	D
Dotting	—	—	—	—	—	—	**0·54**	0·33	**0·35**	**0·23**	**0·21**	0·26	**0·39**	**0·28**	**0·21**	**0·26**	0·01	−0·02	0·08	**0·11**	—	—	0·04	0·12
Choice Reaction	**0·54**	0·33	**0·35**	**0·23**	**0·21**	**0·26**	—	—	—	—	—	—	0·24	0·09	**0·17**	**0·22**	0·12	0·08	**0·14**	**0·13**	0·32	0·07	0·17	0·13
Pursuit Meter	—	—	**0·39**	**0·28**	**0·21**	**0·26**	—	—	0·24	0·09	**0·17**	**0·22**	—	—	—	—	0·09	0·01	0·02	−0·03	—	—	**0·24**	0·08
Intelligence	—	—	—	—	0·01	−0·02	—	—	—	—	0·12	0·08	—	—	0·09	0·01	—	—	**0·23**	**0·21**	—	—	—	—
Number Setting	—	—	—	—	0·08	**0·11**	—	—	—	—	**0·14**	**0·13**	—	—	0·02	−0·03	**0·23**	**0·21**	—	—	—	—	—	—
Ocular Muscle Balance	—	—	0·04	0·12	—	—	0·32	0·07	0·17	0·13	—	—	**0·24**	0·08	—	—	—	—	—	—	—	—	—	—

The significant correlation coefficients (i e those exceeding $2\frac{1}{2}$ times their probable errors) are printed in Clarendon type

The Combined Scores.

In order to find the relation between the combined scores of reaction, dotting, and pursuit meter and accident liability, each score was weighted according to the difference in accident rate of those better and worse than the mean in each test. This involved multiplying the ranks of each subject in reaction by four, in dotting by five, and in pursuit meter by two. These weighted scores were summed for each individual and the total thus obtained was his final weighted score. These final scores were averaged and the accident rate of those better and worse than the mean found The results are given in Table XVIII. This is admittedly an extremely rough method of getting a weighted combined score, and it is accordingly not surprising that the final result only gives a difference of 38 per cent., which is lower than the difference given by dotting alone and practically the same as that given by reaction alone.

Table XVIII.—*Average Accident Rate expressed as a Percentage of the Mean of those better and worse than the Average in the Combined Weighted Scores. (Weighting by means of the differences in Accident Rate yielded by the separate Tests.)*

Group	*Better in Tests.*		*Worse in Tests.*
C	88		112
D	73		127
E	86		113
F	79		121
Weighted Averages	81		119
Difference		+38	
Probable Error of Difference		11·6	

The only really satisfactory method of weighting is by means of the regression coefficients between accidents and each of the tests. Accordingly a second method of weighting was tried, which was the nearest approximation to the correct method that the data would permit. The actual weights used are given by the regression-coefficients in the regression equation of accidents on the three tests.* These involve the coefficients

* The regression equation of x_1 (accidents) on x_2, x_3, and x_4 (the three tests) is—

$$(x_1-\bar{x}_1)=r_{12\cdot34}\frac{\sigma_{1\cdot34}}{\sigma_{2\cdot34}}(x_2-\bar{x}_2)+r_{13\cdot24}\frac{\sigma_{1\cdot24}}{\sigma_{3\cdot24}}(x_3-\bar{x}_3)+r_{14\cdot23}\frac{\sigma_{1\cdot23}}{\sigma_{4\cdot23}}(x_4-\bar{x}_4).$$

The weights are the coefficients of the x's on the right of the above equation and are :—

$$\text{for } x_2,\quad r_{12\cdot34}\frac{\sigma_{1\cdot34}}{\sigma_{2\cdot34}}=r_{12\cdot34}\,\sigma_1\frac{\sqrt{(1-r^2_{13})\ (1-r^2_{14\cdot3})}.}{\sigma_{2\cdot34}}$$

$$\text{for } x_3,\quad r_{13\cdot24}\frac{\sigma_{1\cdot24}}{\sigma_{3\cdot24}}=r_{13\cdot24}\,\sigma_1\frac{\sqrt{(1-r^2_{12})\ (1-r^2_{14\cdot2})}.}{\sigma_{3\cdot24}}$$

$$\text{for } x_4,\quad r_{14\cdot23}\frac{\sigma_{1\cdot23}}{\sigma_{4\cdot23}}=r_{14\cdot23}\,\sigma_1\frac{\sqrt{(1-r^2_{12})\ (1-r^2_{13\cdot2})}.}{\sigma_{4\cdot23}}$$

All this is readily calculable and σ_1, the standard deviation of accidents

of correlation between accidents and each of the tests, but on account of the small range of accidents the correlation coefficients obtained by the product-moment method would probably be unreliable, and so they were calculated by means of a four-fold table. This method of correlation gave the following coefficients of correlation :—

Accidents with reaction	·144
Accidents with dotting	·142
Accidents with pursuit meter	·119

When these were substituted in the formulæ for the weighting (q.v.), it was found that the weight for reaction was $\cdot 00962\sigma_1$, for dotting $\cdot 00381\sigma_1$, and for pursuit meter $\cdot 00290\sigma_1$, so that the scores for reaction were multiplied by ten, those for dotting by four, and those for pursuit meter by three. These weighted scores were summed and averaged, and the accident rate of those better and worse than the mean is given in Table XIX. It will be seen that there is a difference of 48 per cent. between those who pass and fail in the combined weighted tests, and that this difference is more than four times its probable error so that it is fully significant. This method of arriving at the final score is more accurate than that of weighting by the differences, but far less accurate than .weighting by means of the regression coefficients found by the product-moment method. Later, when further data make possible the use of this method, the result will undoubtedly be more satisfactory than that already obtained. In view of the roughness of the present method of arriving at the final score, which admittedly does not use the results to the fullest extent, and also of the fact that the number of accidents actually met with by an individual in a finite time, is very largely conditioned by chance as well as by his proneness, it is most encouraging to find that there is a difference of 48 per cent. in accident rate between those who pass and fail in the combined aestheto-kinetic tests.

TABLE XIX.—*Average Accident Rate expressed as a Percentage of the Mean of those better and worse than the Average in the Combined Weighted Scores. (Weighting by means of the Coefficients in the Regression Equation.)*

Group.	*Better in Tests.*		*Worse in Tests.*
C	85		120
D	64		145
E	91		111
F	72		128
Weighted Averages	**77**		**125**
Difference		+48	
Probable Error of Difference		11·6	

It is difficult to present on similar lines the results obtained from the ocular balance and tremor tests. Both of these tests yielded qualitative results only, and although it would be possible, in the case of hyperphoria at least, to get quantitative results, yet the range of the scores would be so small as to make any conclusion based upon them somewhat unreliable.

It would be possible to make the final score of each subject consist of the number of tests associated with accident proneness in which he had passed. If necessary the tests could be weighted according to their association with accident proneness, but this method would differ from the one employed by not allowing a subject to score in any tests in which he was not above the mean. This method was not adopted. because it was felt that a truer indication of accident proneness would be reached by letting the score obtained in each test play its proper part in the final score, and by resorting to division above and below the mean only when dealing with this final score. It may ultimately turn out that better results are obtained by the rejected method, and if this should be the case there would be no difficulty in properly scoring the results from the ocular muscle balance and tremor tests.

Another method of using the results is to regard them as confirmatory tests in doubtful cases. As a rough way of testing this, the hyperphoria records of those whose final weighted score was within 5 per cent. of the mean on either side were examined. If those whose scores were just better than the mean, but who had hyperphoria, were rejected, and those whose scores were just worse than the mean but who were free from hyperphoria were accepted, the final results would be improved by lessening the total number of accidents of those accepted by six in group C and one in group D.

It is not possible with the present data to treat those with marked tremor in the same way. There were only 16 cases out of 279 subjects in group F, the only large group examined. Of these, six are better than the average in the final score, but they only have one accident between them, whilst ten are worse than the average and have eleven accidents between them. This distribution may be due to a correlation between the aesthetokinetic tests and tremor, but with so few cases it is impossible to determine this. When more subjects have been examined it may be possible to bring the tremor test into line with the others, but at present we must content ourselves with simply noting that it has a connection with accident proneness.

SUMMARY OF THE RESULTS OBTAINED FROM ALL THE TESTS.

When the accident rate of those whose score was below the mean of the group was greater than that of those whose score was above the mean, a plus (+) sign is put; when the contrary is the case a minus sign (−) is put and when the accident rate of those above and below the mean was equal, a sign of equality is put (=). The significant averages are marked with an asterisk.

TEST APPLIED.

Group	Subjects.	Simple Reaction.	Simple Co-ordination.	Choice Reactions. 2 Stimuli.	Choice Reactions. 3 Stimuli	Choice Reactions. 4 Stimuli.	Choice Reactions. 5 Stimuli.	Choice Reactions. 6 Stimuli.	Complications.	Cover up.	Distractions.	Selective.	Dilemma	Changed Position.	1st Time of Testing 5 Stimuli.	Choice and Complication (Mistakes).	Selective (Mistakes).	Variations in Reaction Times	Dotting	Pursuit Meter	Ocular Muscle Balance. Hyperphoria.	Ocular Muscle Balance. Eso-exo-phoria	Ocular Muscle Balance. Alternation and Neglect	Intelligence.	Intelligence (Errors).	Number Setting.	Psycho-galvanic Reflex.
A ..	17	−	+	+	+	−	−	−	−	=	+		=	+	+	+		+	+		+	+	+				+
B ..	23	−	+	+	+	−	+	+	+	+	+		+	+	+	+		=	+		+	+	+				+
C ..	57							=	+			+				−	+	−	+	+	+	−	−				
D ..	100							+	+							+		+	+	+	+	−	−				
E ..	175							+								−		−	+	+				+	−	−	
F ..	279							+								+		+	+	+				−	+	−	
Weighted Averages	(651)	−	+*	+*	+	−	+	+*	+	+	+	+	+	+	+*	+	+	+	+*	+	+*	−	+	−	+	−	+

Relation between Major and Minor Accidents.

It has already been pointed out that no distinction between major and minor accidents was made when determining the relationship between the tests and accident liability. The minor accidents are naturally more numerous than the major, so that the relationship which has been found between certain of the tests and accident liability is in the main a relationship with minor accidents. It is important, therefore, to know whether those who tend to sustain an undue number of minor accidents also tend to have a more than usually large number of major accidents.

The accident records for a year of 14,524 dockyard workers, comprising various trades, were examined and the major and minor accidents for each trade correlated. The results are presented in Table XX. A major accident is defined as an accident involving one day or more lost time.

In the first six groups, the correlation coefficients show a small but significantly positive correlation between major and minor accidents. Fitters show a still smaller correlation value which may in part be due to the relatively smaller number of both major and minor accidents in the group. The negligibly small and negative correlation coefficients in the last three groups cannot be due to less opportunity to sustain accidents, as can be seen by comparing their mean numbers with the means of the other groups. It may be that there is something in the work of these groups that makes their major and minor accidents, or both, less dependent on personal qualities, but the investigators have no knowledge of any such peculiarity.

The partial correlation coefficients for the first six groups show no appreciable increase in value when exposure to risk is kept constant This agrees with Newbold's results and shows that in the period studied the differences in the length of exposure observed affected accident rate to a negligible degree.

The accident rates of the trades, as can be seen from the table, differ, and since the apprentices in groups C and D belonged to these different trades it might appear at first sight that groups C and D should have been divided into their component trades instead of being treated as homogeneous groups. If this had been done there would have been so few in each trade that the results would have been entirely unreliable. To some extent all the apprentices are exposed to similar risk in spite of the differing accidents rates of their respective trades, for they are mainly engaged in learning how to use tools as such. When more observations have been made it will be possible to divide them according to their trades and then the results will be more accurate, but this method must be postponed for the present. This and all other inaccuracies arising from inability to control the factor of exposure to risk tend to mask the effect that personal differences have in the causation of accidents and to obscure the conclusions arrived at in this report, since the failure to take them into account reduces the differences in accident rate between those who pass and those who fail in the tests so that they are smaller than they might otherwise be

Table XX.—*Relations between Major and Minor Accidents among Dockyard Workers.*

Trade	No in Group	Means			Standard Deviations.			Correlation Coefficients.			
		Major	Minor.	Expo-sure.	Major	Minor.	Expo-sure.	Major and Minor	Major and Exposure	Minor and Exposure.	Major and Minor Exposure Constant.
Labourers	6,050	0·05289	0·5342	307·458	0·251	0·963	3·576	**0·138**	0·012	**—0·147**	**0·141**
Shipwrights	3,507	0·02908	0·5349	301·554	0·173	0·926	3·641	**0·170**	0·015	**—0·078**	**0·172**
Boys	429	0·05128	0·9347	308·076	0·241	1·184	3·646	**0 252**	—0·050	**—0·305**	**0·249**
Rivetters	295	0·07797	0 8203	328·728	0·304	1·060	2·921	**0·254**	0·044	**—0·146**	**0·264**
Caulkers	181	0·1271	2·2265	337·209	0·354	2·502	2·569	**0·311**	0·037	**—0·616**	**0·424**
Boilermakers . ..	639	0·0516	0·5117	360·105	0·241	1·061	1·607	**0·356**	—0·019	—0·015	**0·356**
Fitters	2,634	0·02923	0·4465	—	0·179	0·906	—	**0·055**	—	—	—
Drillers	539	0·05566	0·8757	—	0·245	1·016	—	—0·039	—	—	—
Smiths	196	0·07143	0·8061	—	0·277	1·089	—	—0·022	—	—	—
Welders	54	0·07407	1·0185	—	0·325	1·045	—	—0·004	—	—	—

The significant correlation coefficients (i e those exceeding $2\frac{1}{2}$ times their probable errors) are printed in Clarendon type.

Relations between Accidents and Sickness.

The correlation coefficients between accidents and sickness for the dockyard workers included in Table XX, were found and are shown in Table XXI.

Table XXI.—*Correlations between Accidents and Sickness. (Dockyard Workers.)*

Trade	No in Trade	Correlation
Boilermakers	752	·**134**
Welders	54	·108
Caulkers	180	·079
Shipwrights	3,506	·**064**
Fitters	2,781	·027
Labourers	6,020	·**025**
Rivetters	295	—·065
Boys	430	—·**099**
Drillers	540	—·**101**
Smiths	189	—·**219**

It will be seen that they are negligibly small and in part negative. The only sickness records obtainable were those of sicknesses involving lost time and such sicknesses are likely to be more common among the older members of the group. It was impossible to get any reliable data as to age, so that this factor could not be kept constant. Newbold found that the commonest value of the correlation coefficient between age and accidents was somewhere near —·2, and Greenwood and Woods found it to be —·19 and — ·18 for munition workers, so that if the assumption be correct that sicknesses involving lost time are more common among the older employees, then we should expect to find a negligible correlation between such sickness and accidents. Newbold got a series of correlation coefficients between accident and days absent through sickness similar to those in Table XXI. The correlation coefficients obtained by her between accidents and sickness—defined as the number of visits to the surgery exclusive of accidents—were positively significant and somewhere in the neighbourhood of ·3 When sicknesses are defined in this way a psychological factor is introduced which is lacking when sicknesses are defined as loss of time through illness. With some people there is a tendency to report sick at the least provocation and such " sickness " may in many cases have a large imaginative element in it and really only represent a disinclination to work engendered by some other environmental maladjustment. It is not surprising that such " sicknesses " should be positively correlated with accidents, since they represent temperamental instability rather than physical ailments. Sicknesses involving loss of time are far freer from this temperamental element and will tend to occur more among the old than the young, and so there is no reason to expect a correlation between these and accidents.

Relation between Accident Proneness and Industrial Efficiency.

If certain tests are found to have a connection with accident proneness, it becomes important to see what is the relation between these tests and industrial efficiency. For, if people are not to be admitted to particularly dangerous occupations because they fail to pass certain tests which indicate that they are unduly liable to sustain accidents, then the point arises whether those who would be rejected would be more or less efficient than those who would be accepted.

In a few years' time the industrial proficiency records of groups C, D, E, and F, and also of certain others for whom arrangements have been made for testing, will be available, and the various measures of efficiency can be correlated with the accident tests. In the meantime we must content ourselves with comparing the two halves of group E. It will be remembered that this group was divided equally into those who had failed in the passing-out examination for the Royal Air Force apprentices and the top boys in the next entry. Table XXII shows the scores of the two groups in the various tests. In each case the industrial failures get worse scores than those who are industrially efficient, and their accident and sickness* rates are also greater. These results must await confirmation, but it is interesting to note that they are consistent at least with the hypothesis that those who fail at the tests not only have more accidents and sickness than those who pass, but are also less efficient in their occupations as measured by the practical and theoretical examinations that Royal Air Force candidates are required to pass before they can be rated as competent members of the Force.

TABLE XXII.—*Comparison of those who had failed in the Passing-out Examination of the R.A.F., and those who were top in the next entry.*

	Reaction.	*Dotting*	*Pursuit Meter.*	*Intelligence.*	*Number Setting*
Failures	98·8	99·5	98·1	87·5	95·1
Top in next entry†	100·3	100·0	102·4	113·2	105·3

	Total Accident Rate.	*Sickness Rate.*	*Major Accident Rate.*
Failures	110·9	121	141
Top in next entry ..	87·5	77	51

* Sickness is defined as visits to the surgery excluding accidents and redressings.

† Practically all of these have since passed their final examination.

Conclusions.

(1) From the foregoing experiments the definite conclusions can be drawn that inequality in accident liability is not solely determined by external factors, or by chance, but is due in an appreciable degree to measurable individual differences. Even complete knowledge and perfect measurement of such personal differences will never make it possible to say with certainty whether any particular individual will or will not sustain an accident under given circumstances, but the present results suggest that it is practicable to determine in a rough way the probability of any individual sustaining an undue number of accidents, and as more research work is done and the methods become more refined, this probability should tend to approximate more and more to certainty. It must, however, be borne in mind that at present the reliability of the tests has not been established, and until this is done they cannot safely be used for prognosticating the accident proneness of individuals.

(2) A relationship has been shown to exist in the subjects examined between accidents on the one hand, and poor "aestheto-kinetic co-ordination" and nervous instability on the other. No relation has been found between accidents and the higher intellectual processes. The intermediate processes involving the special abilities and more highly integrated aestheto-kinetic co-ordination have not been examined.

(3) There is a slight indication that the accident prone are industrially inefficient and more liable to report sick, and so react unfavourably to their total environment. This needs confirmation.

(4) No attempt has been made to distinguish between specific and general factors in personal proneness to accidents. This will have to be examined in a further enquiry.

(5) A positive correlation has been found to exist between major and minor accidents in most of the groups examined. The relationship differs in different trades and in some does not seem to exist.

(6) The final weighted results show a difference of 48 per cent. in accident rate between those above and those below the averages in the tests.

The investigators wish to acknowledge their special indebtedness to two of their colleagues, Miss E. M. Newbold and Dr. E. Schuster; Miss Newbold for her constant help and criticism in connection with the statistical side of the work, and Dr. Schuster for the various pieces of apparatus he has so ingeniously constructed. To the subjects who allowed themselves to be tested for purposes it was impossible to explain in detail and for ends which could not possibly benefit them personally, we are also indebted in a special way. Their co-operation has helped forward the understanding of a difficult problem, and the knowledge of this is their only reward.

APPENDIX I.

QUARTILE DISTRIBUTION OF ACCIDENT RATES.

In the body of the report a subject was accounted to have failed if his score was below the mean, and to have passed if his score was above the mean. This method necessarily implies the rejection of half the subjects and the acceptance of the other half, but if these tests were ultimately used for practical purposes this might prove in certain circumstances an undesirable way of dealing with the labour supply, which must vary from time to time and from trade to trade.

Table XXIII gives the quartile distribution of the groups C, D, E and F. The method adopted was to rank the final weighted scores (obtained by the regression coefficients) for each group, and then to take the top, second, third, and bottom 25 percentages and express the average accident rate of the individuals whose scores fell into these respective categories, as a percentage of the mean of the group.

Table XXIII.—*The Average Accident Rate expressed as a Percentage of the Mean of the Group for the Quartiles of the Weighted Final Scores in Reaction, Dotting, and Pursuit Meter combined.*

Group.	Top Quartile		2nd Quartile.		3rd Quartile.		4th Quartile.	
	Accident Rate.	No	Accident Rate.	No.	Accident Rate.	No	Accident Rate.	No.
	Per cent.		Per cent		Per cent		Per cent	
C ..	49	14	97	14	124	15	127	14
D	61	25	48	25	121	25	170	25
E	67	42	114	45	105	46	111	42
F	62	70	85	70	111	69	147	70
Weighted Averages	**62**	(151)	**89**	(154)	**112**	(155)	**139**	(151)

Difference in accident rate between the Top Quartile and the other three Quartiles combined = 51 per cent , probable error of difference = 13·43.

Difference in accident rate between the Bottom Quartile and the other three Quartiles combined = 51 per cent ; probable error of difference = 13·43

The difference in accident rate between the top quartile and the other three combined, and the bottom quartile and the other three combined turns out in both cases to be 51 per cent , which is slightly larger than the differences between the accident rates of those above and below the mean. This shows that the tests would yield equally satisfactory results if they were used to accept or reject fewer than 50 per cent. of a given population. This method has not been adopted in the report because at this stage it is inadvisable to attempt to draw conclusions as to the best way of using the tests for practical purposes The object throughout has been merely to show the connection between accident liability and certain measurable personal factors When more work has been done along the lines indicated in the report it will be possible to devise the best methods of applying the tests for specific purposes.

APPENDIX II.

A DESCRIPTION OF THE APPARATUS USED

CHOICE REACTION TIME APPARATUS.

This apparatus differs essentially from the usual form of reaction time apparatus in the fact that the stimulus and response are recorded electrically on a roll of paper instead of by means of a stop-watch or chronoscope. It consists of two parts, one for the subject and one for the experimenter.

The subject's part, Fig. 1, consists of a closed rectangular box furnished with six response buttons, A, situated each $2\frac{3}{4}$ in. from a fixed starting point, B By each response button is an index, C, showing to which

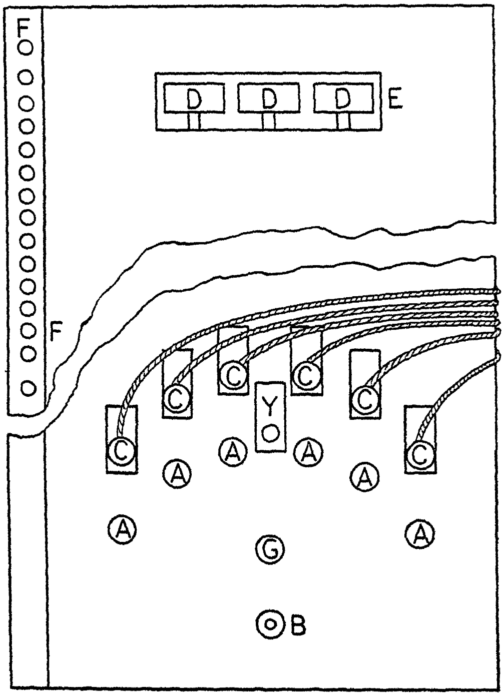


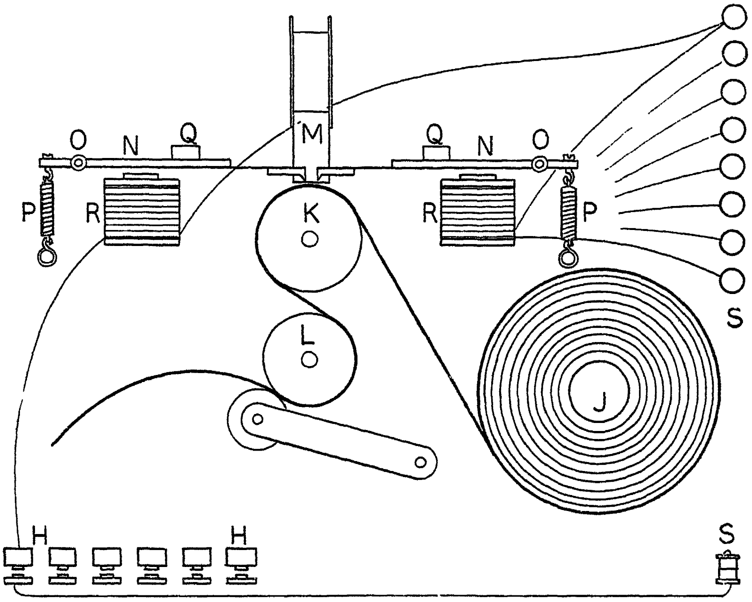
FIG. 1.

stimulus each response corresponds. Three of these indexes are discs of celluloid coloured appropriately to represent the three visual stimuli, red, green and white ; two are marked " B " and " Z," corresponding to " bell " and " buzzer," the two auditory stimuli ; and the sixth is marked " T," for the tactual stimulus. The three visual stimuli, D, consist of squares of coloured celluloid mounted on levers and capable of being raised above a slit, E, by means of electromagnets, which lower one end of the levers and raise the other. The bell and buzzer are contained inside the subject's box. The tactual stimulus consists of a blunt metal point on a lever. When this stimulus is given the point is caused to move through a hole in the starting point, B, and touch the subject's finger as it rests there. All these stimuli are actuated electrically from the experimenter's box.

On a ledge at the side of the subject's box are fifteen terminal screws, F. To six of these are connected wires from the experimenter's box. these carry the current which actuates the stimuli. Another six wires also connect the subject's and experimenter's boxes and convey the current which records the response. Each of these sets of six wires is bound into a cable, all the wires having insulating bindings of different colours. Two of the terminals are connected to a 4-volt accumulator, which supplies the current to work the bell and the buzzer. The remaining terminal is connected to the negative pole of a battery giving 12 volts.

A seventh response button, G, for use in simple reaction experiments, is situated near the starting point, B.

The experimenter's box, of which the essential parts are shown diagrammatically in Fig 2, combines the time recording apparatus and the device



FIG, 2.

for giving the stimuli. The six stimuli are given by means of six keys, H. of the Morse type, each being labelled to indicate which stimulus it will present when pressed In order to record the reaction time, a gramophone motor contained in the experimenter's box causes a roll of paper, J, to unwind at a uniform rate over rollers, K and L. As the paper passes over roller K, it passes under a bi-coloured typewriter ribbon, M. The ribbon is wound on two spools which can be rotated by hand when a fresh portion is required Twelve pens are arranged, six on each side of the ribbon Six of these record the moment when the stimulus is given by being caused to mark the roll of paper through the black side of the ribbon. The other six record the response by marking the paper through the red side of the ribbon The pens are mounted on steel bars, N, pivotted at O, and held in position by springs, P, and brass bars, Q Beneath each of these steel bars is an electromagnet, R When the experimenter depresses a stimulus key an electric circuit is made through the appropriate electromagnet and the bar above it is attracted, causing a pen to impinge on the ribbon, thus marking the paper as it passes over the roller, K. An exactly similar process takes place when the subject presses a response button.

The electrical connections between the experimenter's and subject's boxes are made from the terminal screws, S, to which are connected the twelve wires from the subject's box. From one terminal screw connection is made with the positive pole of the 12-volt. battery.

The rollers K and L, the pivots O, and the bars Q, are all held in position between two brass plates. The remaining devices on the experimenter's box are the winding handle for the motor, the handle to start and stop the motor, and the regulator for regulating the speed at which the roll of paper unwinds.

The pair of pens recording the stimulus and response for any particular stimulus are situated exactly opposite to one another, so that if the subject makes a correct response the red mark indicating the response on the roll of paper is in the same line as the black mark showing the stimulus. If an incorrect response is made the red mark is out of line with the black.

Uses of the Apparatus.

(1) *Choice Reaction.*—The use of the apparatus for measuring choice reaction time will have been gathered from the foregoing description. The subject stands with his forefinger resting on B in Fig 1. A stimulus is given by the experimenter depressing the appropriate key, H, and the subject has to respond by putting his forefinger on the corresponding response button, A. Only one finger is used throughout. Both stimulus and response are recorded on the roll of paper and the reaction time can be measured directly to 1/100th second by measuring the distance between the stimulus and response marks A metal scale is provided for the purpose. The motor is normally regulated so that 1/32nd inch on the paper represents 1/100th second.

(2) The indexes, C, can be taken out of the brass strips into which they fit and rearranged in any desired order, thus breaking any position association which has been previously formed.

(3) Metal caps can be placed over the indexes, C, so that the subject has to make his responses by memory.

(4) *Simple Reaction*—To use the apparatus for simple reaction (i.e., reaction not involving choice), the index corresponding to the desired stimulus is fixed into the brass strip, Y, Fig 1. The subject has to keep the button, G, continually depressed and when the stimulus is given he responds merely by removing his finger from the button. Simple reaction times to visual, auditory and tactual stimuli can thus be measured. In the case of the tactual stimulus the subject has to use two fingers, one resting on B and the other keeping G depressed He responds in this case by removing both fingers.

THE NUMBER-SETTING TEST.

This test was devised with a view to measuring intelligence expressed through a mechanical rather than a scholastic medium. The apparatus (Fig. 3) consists of a metal plate, A, with nine circular holes, B, pierced in it. At the side of the holes is a scale, C, numbering each hole consecutively from 1 to 9, and parallel to this scale is a bar, D, with three movable riders on it. At right angles to the scale are two rows of knobs, one row, F, coloured white and the other, G, coloured green. There are six knobs in each row, and they are arranged in pairs, one white knob and one green in each. Above the knobs is a scale, H, with two or three numbers corresponding to each pair of knobs engraved upon it

When one of the white knobs is pushed forward it causes white spots to appear in the holes against the numbers which are engraved above that knob on the scale, H. On the other hand, when a green knob is moved forward, it causes white spots to disappear from the holes corresponding to the numbers engraved above it. An example will illustrate

this most clearly Suppose white spots were already present in holes 5 and 6, and the white knob 1, 6 were pushed forward: the result would be that a white spot would appear in hole 1, there being one already in hole 6. Similarly, if instead of the white knob the green knob, 1, 6 had been moved

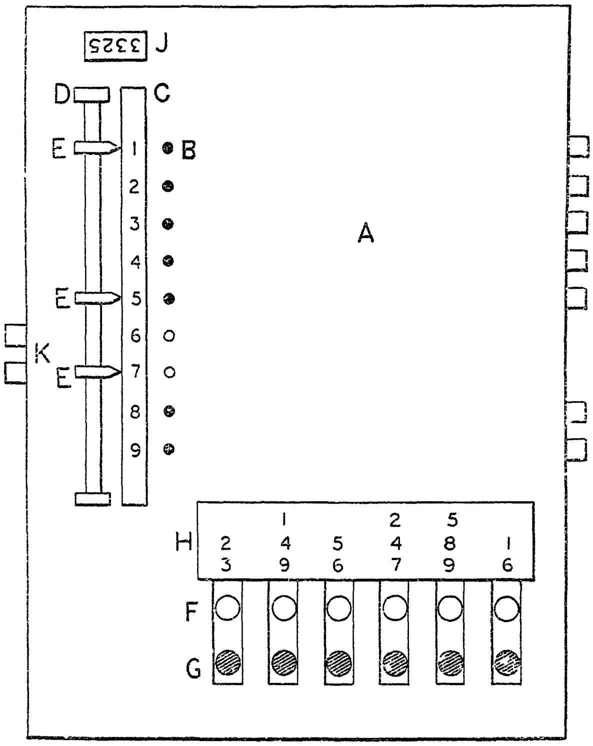


FIG 3.

forwards, the white spot would disappear from hole 6 only, as there was no white spot in hole 1 to remove By moving various white and green knobs in succession, white spots can be made to appear in many different combinations of holes. The use of the riders, E, is to indicate the required combination They are moved along the bar, D, until they point to the three required holes The subject has then to press forward knobs F and G one at a time until white spots appear in the three required holes and in no others. The number of knobs the subject moves to achieve this end is recorded on a Veeder counter, J.

The mechanism by which the white spots are caused to appear and disappear is as follows:—Passing under each hole at right angles to the scale, C, is a metal rod, K, Fig 4, having one or two triangular pieces of brass (T) fixed to its under-surface and a white patch on it At right angles to these are other rods, L, each bearing a stud, M, and a knob, either F or G. When the knob is moved forwards the stud, M, is made to press on the right or left side of a triangular projection and consequently moves the bar, K, either to the left or right, respectively, thus bringing the white patch under the hole, B, or else removing it if it is already there Each of the rods, L, is provided with a spring so that when it has been moved forward it returns automatically to its original position. The rods which cause two or three white spots to appear simultaneously have, of course,

two or three studs on them and act on two or three of the rods, K, at the same time. The experimenter can remove any white spots at will and without making a record on the Veeder counter by pressing on the end of the rods K.

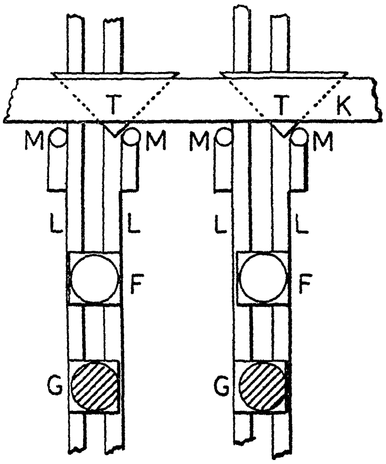


FIG 4

Theoretically there are 84 possible combinations of three numbers out of nine, but practically some of these are impossible owing to the numbers chosen for each knob. For example, if the combination required has a 2 in it, it must also have either a 3 or a 7, as can readily be seen by studying the scale, H. In actual practice only 48 three-figure combinations can be obtained. Of these—

3 take 1 move; 1 takes 2 moves; 13 take 3 moves;
22 take 4 moves, 3 take 5 moves; and 6 take 6 moves.

Uses of the Apparatus.

Results may be scored in two ways, either by the time taken to do a set task or by the number of moves taken to do the same task. As the combinations which can be obtained differ both in difficulty and the number of moves each required, the task must be the same for all subjects if comparisons are to be made. The task may be set in two ways :—(1) It may consist of obtaining a certain number of combinations requiring varying numbers of moves each ; or (2) it may consist of obtaining a certain number of combinations requiring the same number of moves each, e g., three. In practice it is found that the best results are obtained by measuring with a stop-watch the time taken to do the task, although this involves an obvious source of inaccuracy, viz , the time taken by the experimenter to clear a completed combination and set a new one. This can to some extent be obviated if the experiment is conducted throughout by the same experimenter with an unvarying technique.

THE SELF-RECORDING DOTTING MACHINE.

This apparatus designed by Dr. Schuster (Fig. 5) is a modification of the McDougall dotting machine. It consists of a gramophone with a motor driving an aluminium platform, 14½ in in diameter, at a rate of one revolution in 39 seconds. In the lid of the containing box is a slit, A, 1 in. by 5½ in. A paper disc equal in size to the aluminium platform, has 346 small circular holes punched out of it These holes are arranged in a spiral strip, which makes three complete turns about the centre of

the disc. The arrangement of the holes in the strip is approximately the same as in the paper tape designed for the McDougall dotting machine. That is to say, they are equally spaced along the length of the strip, but are at distances varying in an irregular manner from its centre. The

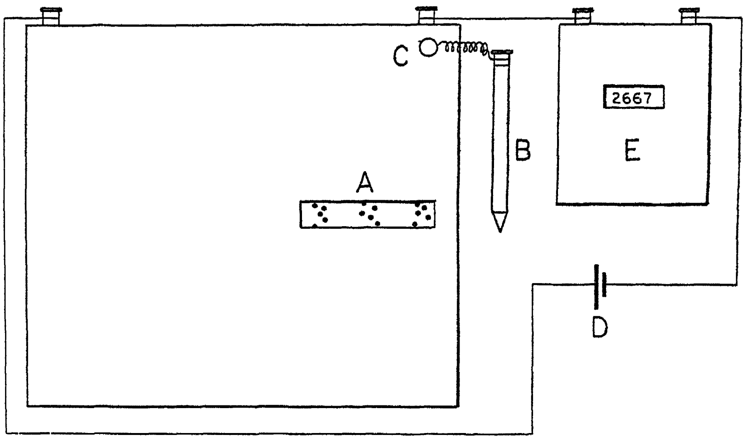


FIG. 5

paper disc is clipped to the platform and the lid of the machine closed so that only a small portion of the disc is visible through the slit, A When the motor is started the holes in the disc move under the slit away from the subject, those nearer the centre moving slowly and those further moving more quickly. The subject is provided with a stylus, B, furnished with a platinum point and connected by a flexible wire to a terminal screw, C. This terminal, C, is in an electric circuit containing in series a 2-volt accumulator, D, an electromagnet operating a Veeder counter, E, and the platform of the machine.

The subject is required to dot the holes in the paper disc as they pass under the slit. This he does with the stylus, and every time he makes a successful hit electric contact is established between the stylus and the platform and a circuit is made through the electromagnet, causing the Veeder counter to record the hit The subject starts at the central end of the spiral of holes where the movement is slow and continues right to the end of the spiral, where the movement is far too rapid for him to dot all the holes. The total number of holes he has successfully dotted can then be read directly from the Veeder counter.

THE PURSUIT METER.

The pursuit meter is a much simplified form of Miles' apparatus,* presenting a similar task to the subject but operating in an entirely different way The essential features of the machine now described are two white pointers, A and B, Fig 6. Each is mounted on a long arm pivoted, in the case of A, at the centre of a ratchet wheel, C, and fixed in the case of B, at the side of a brass disc, D C is vertically above D, and the two can rotate independently about the same axis. The pointer, A, is mechanically constrained to move in an arc of a circle with a varying velocity pattern. This is effected by means of two cranks of unequal throw and period connected by a link, the arm carrying the pointer, A, being connected with

* W. R. Miles, Journ of Experimental Psychology 1921, **4**, 77.

the link about 1½ ins. from its free end. The pointer, B, on the other hand, is under no mechanical constraint and has to be moved by the subject by means of the knob, F, so that the two pointers are kept continually as close together as possible.

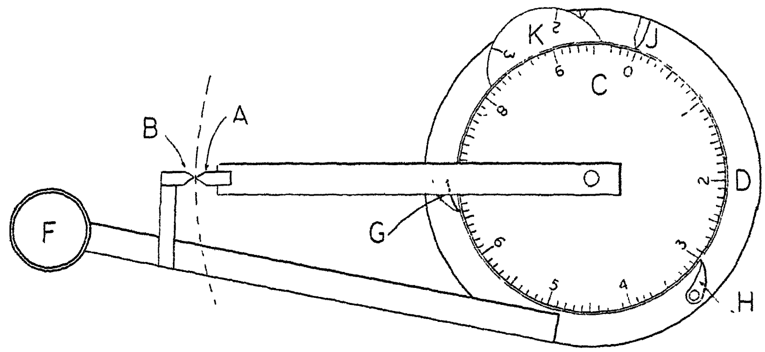


FIG. 6

Two pawls engage the ratchet wheel C, the one, G, being fixed to the arm on which the pointer, A, is mounted, and the other, H, being fixed on the disc, D C can rotate freely round its axis in one direction, so that when there is any differential velocity between the two pointers in one direction the pawls cause C to rotate relatively to D, but if the two pointers are kept absolutely together, C does not rotate. Thus, differences in movement between the pointers in one direction are integrated, the total amount of differential movement being represented by the amount of rotation of C C is graduated and the number of divisions through which it has turned can be read by means of an index pointer, J, mounted on the disc, D. C can be set to zero by hand at the beginning of each experiment. A small wheel, K, records the number of complete revolutions of C

The cranks are actuated by a gramophone motor fitted with a simple stopping device, so that when the motor is started it runs for a fixed length of time and then stops automatically. This ensures that each subject shall have exactly the same task to perform.

The pointer, A, can be made to move in any one of four definite velocity patterns at the will of the experimenter This is done by means of a small handle which alters the position of the link connecting the two cranks.

To use the apparatus the experimenter starts the motor and the subject has then to move B by hand, so as to keep it as close to A as possible. The deviations from the correct movement required are summed by the ratchet and pawl device, and the score is read directly from the graduations on C. The speed with which A moves can be regulated by an ordinary gramophone regulator.

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MEDICAL RESEARCH COUNCIL.

INDUSTRIAL
FATIGUE RESEARCH BOARD.

REPORT No. 39.

The Relation of Atmospheric Conditions to the Working Capacity and the Accident Rate of Coal Miners.

By H. M. VERNON, M.D., and T. BEDFORD, B.Sc.
(assisted by C. G. WARNER).

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PREFACE.

The relation of the worker's physical environment to his well-being and efficiency has been explored in several of the investigations undertaken by the Board, and abundant evidence has been adduced to show that physiologically unfavourable conditions in this respect may often have a detrimental influence on working capacity, particularly where occupations involving heavy muscular effort are involved, such as many in the tinplate[1], iron and steel[2], and glass industries[3].

In coal-mining, where the temperature is often high and the work arduous, the same effect would be expected, but the evidence on this point hitherto obtained is rather slight and contradictory. It seemed therefore desirable to arrange for some special investigation as to the actual difference in the working capacity prevailing under existing conditions in the hotter and cooler seams respectively, and in accordance with the recommendations of the Health Advisory Committee of the Department of Mines, the concurrence of that Department was obtained in the extension of an inquiry, already in progress by Dr. H. M. Vernon and Mr. T. Bedford into the atmospheric conditions in coal mines, to cover this point.

The index of working capacity usually adopted, namely output, could not be applied in this instance owing to the large variations in the ease of getting coal, and accordingly two other measures have been substituted. The first consists in the duration of the rest pauses taken from work. As the authors show elsewhere[4], work involving heavy muscular effort is never truly continuous, but consists of a series of spells of activity interrupted by short pauses voluntarily taken by the workers. The relative duration of these spells and pauses has been taken as an approximate measure of the working capacity. The second measure is the time required to carry out a given task, in this particular instance the filling of a tub, on the assumption that an increase in this time denotes a corresponding reduction in working capacity. In addition, some information has been obtained on the relation of atmospheric conditions to accident incidence.

The report shows that there is a heavy loss of working time, due to resting, in the hot seams as compared with the cool, and although the present investigation, being based on actual observation of the colliers concerned, was necessarily limited in scope

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[4] VERNON, H. M, AND BEDFORD, T. (1926): Rest Pauses in Heavy and Moderately Heavy Industrial Work.—*Report No* 41. (*In the Press.*)

and dealt in fact with the different seams in only two collieries, the consistency with which working capacity is shown to be smaller in the hotter seams suggests that the same effect would hold generally throughout the coal industry.

These rest pauses are taken almost unconsciously, and under existing conditions are probably actually necessary in the interests of the worker. Economically, however, they are clearly one source of loss of production, and if the total number of men working in hot seams could be ascertained, this would probably be found to be an important one.

The same conclusion is indicated by the comparison of the tub-filling times and the accident rates.

The question then arises as to how this loss can be prevented or reduced. The natural temperature and humidity of the workings cannot, of course, be controlled, but one possible method of ameliorating conditions, namely increase in air movement, is indicated in the report. This suggests, in short, that ventilation that is adequate for the shallower and cooler seams is insufficient for the deep and hot seams. The Board understand that the Committee on Temperature in Deep and Hot Mines, of the Institution of Mining Engineers, is already engaged on the study of this question, and they think that when its work on the engineering side has solved the practical problem of securing increased ventilation in seams where this is called for, not only will discomfort on the part of the men employed tend to diminish, but a notable increase in output will result.

January, 1927.

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January, 1927.

The Relation of Atmospheric Conditions to the Working Capacity and the Accident Rate of Coal Miners.

By H. M. VERNON, M.D., and T. BEDFORD, B.Sc, *Investigators to the Board*, assisted by C. G Warner

CONTENTS.

Introduction.

It is usually considered that at high temperatures the efficiency of miners tends to fall off, but there is no general agreement as to the extent of the deterioration, or the temperature at which it sets in. As the result of his observations on Cornish tin miners, Haldane (1904) came to the conclusion that hard work is practically impossible at a wet bulb temperature above 80° F. Orenstein and Ireland (1922) made an investigation in a gold mine in South Africa, their method being to put a native boy to work on a rotary ergometer for four hours daily in working places at various depths, whilst another boy was tested with a hammer ergometer. The cooling power of the air was measured by means of the dry and the wet kata-thermometer, and temperatures as high as 88° (d.b.) and 87° (w.b.), were experienced. As the result of the ergometer observations, it was concluded that at dry kata cooling powers of 1, 2, 3, 4, and 5, the working efficiency was reduced by 50, 40, 30, 20 and 10 per cent. respectively below

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that experienced at a cooling power of 6. Again, T. D. Jones (1925) states, though without giving exact data, that the coal miners working in a district in a South Wales colliery where the temperature was 83° (d.b.) and 81·5° (w.b), produced only about 40 per cent. the output of other men working under more favourable temperature conditions.

On the other hand, Moss (1925) records that men working in two stalls at Pendleton Colliery, where the temperature was 100·5° (d.b.) and 86·5° (w.b), produced more coal than the average for the pit, though admittedly the men were some of the best workers, and owing to the excellence of the roof, they could get the coal with a minimum of effort. Again. Moss found that when a mechanic was allowed to work on a bicycle ergometer for four half-hour periods daily, at wet bulb temperatures ranging from 66° to 90°, his mechanical efficiency was greater at the higher temperatures than at the lower ones. The temperature was raised gradually from day to day, and Moss states that the increase of efficiency may have been due " to muscular acclimatisation to work, and not to increased air temperatures " In any case, efficiency did not fall off at high temperatures, but it must be remembered that the man was working under entirely different conditions from those experienced by coal miners The collier who is underground for about 7½ hours daily and is working at the coal face for 6 hours. does not concentrate his energies on a few half-hour bursts, but distributes them more or less evenly over the working day.

The influence of atmospheric conditions on working capacity and on health is likely to become an increasingly important problem in the future, as the shallower seams are worked out and the deeper seams are attacked Hence it seemed to us very desirable that further information on the subject should be obtained. To this end, we made systematic observations at two adjacent collieries (situated in the Eastern Division) for a period of five months. One of the collieries (colliery A) was selected because it offered a very wide range of temperature conditions. In the upper seam (C.), which is 5 ft. to 6 ft. thick, and consists of steam coal, we made investigations at working places situated 540 ft. to 660 ft. below the surface, and the temperature was as low as 63° (d.b.) and 59° (w.b) in some of them. The lower (D.) seam, which consists of household coal and is likewise 5 ft. to 6 ft. thick, was worked from two pairs of shafts. From those at the upper end we reached workings which varied in depth from 1,266 ft. to 1,425 ft. From the other shafts we reached a number of workings which varied in depth from 1,545 ft. to 1,725 ft. Owing to a fault the seam dipped at its lower end about 1,000 ft. in a distance of 1,000 yards, and then continued at the usual slight dip of 1 in 12. The workings here reached a depth of 2,655 ft. to 2,715 ft., whilst the temperature was as high as 89° (d.b.) and 82° (w.b.). At the adjoining colliery (colliery B),

the nearest boundary of which was only $1\frac{1}{8}$ miles away, we visited workings in the D. seam (which here is 3 ft. to 6 ft. thick) at depths of 1,700 ft. to 2,150 ft. Also we visited workings in the F. seam, which is $4\frac{1}{2}$ ft. in thickness, at depths of 2,100 ft. to 2,200 ft. and in the E. seam (5ft. to $6\frac{1}{2}$ ft. thick), at depths of 1,450 ft. to 1,600 ft. In consequence of the more moderate variations in the depth of the working places, the temperatures did not differ so greatly as at colliery A. The lowest temperature met with was 77° (d.b.) and 69° (w b.), and the highest, 87° (d.b.) and 80° (w.b.).

Method of Investigation.

The usual method of testing the efficiency of industrial workers under various conditions is to measure their output, but such a method is impossible when we have to compare colliers who are hewing coal in different working places. Even in the same working place the ease with which the coal is got varies greatly from day to day, and it would be necessary to measure the output of a man over a period of several weeks in order to obtain a fair index of his working capacity. In different working places, even if they be situated in the same seam, the ease with which the coal is got varies still more, whilst in different seams the working conditions may be so different that output comparisons may be absolutely futile as a measure of working capacity. We were therefore driven to devise tests which would apply almost equally to all colliers, whatever the ease or difficulty of their working places The tests adopted were two in number, viz., a rest-pause test and a tub-filling time test.

As the result of observations in various heavy industries, we found that the men invariably take short rests from work every few minutes, and the more arduous the work the longer and more frequent are the rests (*cf.* Report No. 41). They are taken spontaneously, in consequence of fatigue, and their duration affords a measure of the fatigue experienced. We have obtained evidence in support of this statement by making systematic observations on colliers in the various working places above referred to. We generally reached the working place selected at about 9 30 a.m., and after setting up our kata-thermometer apparatus, we made observations on the air velocity and temperature at a spot as near as possible to where the collier was usually standing. This was about three feet from the coal face, and the instruments were fixed at what was roughly the chest height of the men Often we could not make these observations until the men were taking their meal (snap time), or after they had finished work for the day, at about 12.15 p m. ; but we tried to get two sets of observations when possible. During the rest of our stay we noted down every cessation from active work to the nearest quarter-minute, and we split up the rest pauses into three categories, (*a*) voluntary rests, (*b*) involuntary rests (due mostly to the men waiting for tubs, and occasionally to their standing

clear from the coal face in order to avoid a fall of coal after "barring," or to the collier (or hewer) standing by for a few moments in order to allow the trammer (or filler) to clear coal from his working position), and (*c*) time spent in talking about the work with a mate or a deputy. The average rests per hour falling in these three categories are shown in the Tables of data recorded below, and their relative importance is discussed in Report No. 41.

One investigator was generally able to note down the rests taken by two colliers, and the period of observation of all the men investigated averaged 96 minutes, snap time being excluded and ignored. The investigator was likewise able to estimate the tub-filling time. The tubs or trams hold about 10 cwt of coal, but they varied somewhat in size in the different seams, so their average content was ascertained over a three-month period, and all the times quoted are corrected to a 10 cwt. content. Tub filling is more especially the work of the trammer, but the collier usually assists during part of the filling, and in such a case the times taken by the two men were added together The number of tubs filled during the period of observation varied a great deal, and on an average the time was ascertained for 5·2 tubs in each working place. The mean time varied between the extremes of 6 and 15 minutes, 8·0 to 8·9 minutes being the most frequent, as can be gathered from the following data :—

Mean tub-filling time in minutes	6–	7–	8–	9–	10–	11–	12–	13–	15–
Number of occasions ..	8	13	23	17	5	6	1	1	1

This tub-filling time is the average for the working place, whether one or more colliers were present, and whether they were helped by a trammer or not (for in some instances the colliers did the whole of their own filling, and transported the tubs to the haulage roads).

Rest pause observations were made on 124 colliers in all, and upon 14 trammers. The rests taken by these trammers were noted only when they were in the working place, filling tubs, setting props, and assisting the colliers in other ways, including occasional bouts of hewing. Such time as they were absent on their duty of pushing the full tubs to the haulage road and bringing back empties, was ignored. At first it was decided to exclude the rest-pause data obtained for trammers, but as their average rests closely corresponded with those of the colliers, it was decided to include them. Probably the work of the trammers is physically about as arduous as that of the colliers, and for this reason they need to take as much rest.

It should be understood that we never paid more than one visit to a working place, so that all our observations relate to different men. We do not think that our presence disturbed them at their work as we did not speak to them, except on arrival, unless first spoken to. Occasionally they asked us why

we were taking notes, and when we explained that they were made with a view to improving working conditions such as ventilation, they accepted the statement without demur, and were quite friendly. The men investigated were chosen for us by the management, and were considered by them to be good average workers. They appeared to us to work to the best of their ability, and not to limit their output in any way.

The kata-thermometers used by us were held in a clamp which was fixed to a brass rod, 15 inches in length. This was screwed into the head of a light metal photographic tripod stand. Thereby the bulb of the kata could be fixed at any height from 6 in. to 5½ ft. above the ground, however irregular it might be. The wet and dry bulb temperatures were taken by means of standardised Edney sling hygrometers When these instruments are whirled round about 250 times a minute, they take up the air temperature within 1½ minutes

Working Capacity in relation to Wet Kata Cooling Power.

In the light of previous investigations, it seemed probable that the cooling power of the air, as indicated by the *wet* kata-thermometer, would prove to be the best index of atmospheric conditions in relation to working capacity As the result of a large number of experiments on himself and on other subjects, Haldane (1905, 1907) came to the conclusion that for men performing muscular work in warm atmospheres the wet bulb temperature is the only index of comfort, and that the dry bulb temperature is immaterial. He pointed out, however, that the endurable limit of wet bulb temperature is considerably raised if the work is done in a current of air, so his results tend to support the use of the wet kata-thermometer as an index, though this instrument was not invented by Leonard Hill till some years later One of us (Vernon, 1923) repeated and extended Haldane's observations on the wet bulb temperature, and fully confirmed them. Also it was shown that at a given air velocity the cooling power of the wet kata depended only on the wet bulb temperature. It was immaterial whether the dry bulb temperature was only 1° F. higher than the wet bulb, and the air was consequently almost saturated with moisture, or whether it was 10° higher, and the air was consequently about 60 per cent. saturated. It should be realised, however, that this apparent negation of influence to the dry bulb temperature is not genuine, for the wet bulb temperature necessarily carries a dry bulb factor with it. Supposing that moist air with a dry and a wet bulb temperature of 70° is warmed up till its dry bulb temperature reaches 80°, the wet bulb temperature automatically rises to about 74°. If it is warmed to a dry bulb temperature of 90°, the wet bulb automatically rises to about 78°, and so on, each rise of 1° in the dry bulb causing a rise of about 0·4° in the wet bulb.

The data to be described show that the wet kata cooling power is a better index of atmospheric conditions in relation to

TABLE I—*Rest pauses in relation to wet kata cooling power.*

Range of wet kata cooling power.	Observations.		Rests per hour in minutes.				* Tub-filling time in min	Temperature		Cooling power		Air vel in ft per min	Sensation of freshness	Effective temperature.
	Men	Tubs	Voluntary	Involuntary.	Talking	Total		Dry bulb.	Wet bulb	Dry	Wet			
								°	°					
19 to 16 ..	10	6	4·4	1·8	1·1	7·3	8·0	73·5	66 0	5·6	18·6	87	4·4	65·8
15 to 14 ..	16	8	5 0	0·7	1·0	6·7	8 6	70·1	65 6	4·8	14·6	34	3·7	65·8
13 to 12 ..	17	9	5·4	2·7	0·9	9·0	8 5	81·7	73·6	3 1	12·9	46	2·9	75·3
11 to 10 ..	47	28	5 0	3·7	1·3	10·0	9 2	80·8	74·1	2·8	10·8	25	2·4	75·8
9 to 8 ..	42	21	7·3	3·1	0·7	11·1	9·1	82·4	76 2	2·4	9 0	18	1·4	77·8
7 to 5 ..	6	3	8·1	12·4	1·9	22·4	9·6	86·2	79·3	1·7	6·4	10	0·7	81·2

* The equation of the straight line fitted by least squares to the tub-filling times in minutes in terms of the wet kata cooling powers is

$$y = - \ 1531\, x + 10\ 67.$$

The slope of this line is given by the co-efficient — ·1531 and the probable error of this slope (given by the formula $\cdot 67449\ \frac{\sigma_y}{\sigma_x}\sqrt{\frac{1-r^2}{N}}$) is 045

Hence the rise in time with the fall in the wet kata cooling power is significant

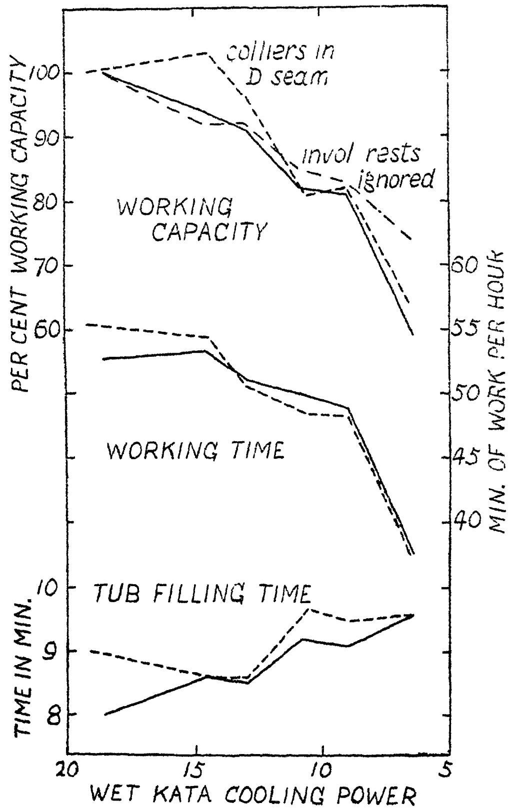
working capacity than any other measure yet suggested In order to bring out the relationship between cooling power and working capacity, we have split up our 138 observations into six groups, and it will be seen from Table I that the mean wet kata cooling power of these groups ranged from 18·6 to 6·4, the associated dry kata cooling power ranging from 5·6 to 1·7. With decrease of cooling power, the voluntary rests from work rose fairly steadily from 4½ min per hour to 8 min, whilst the involuntary rests rose, somewhat irregularly, from about 1—1½ min. to 12½ min. The rests taken in talking about work were generally about 1 min. per hour, and the total rests taken ranged from a minimum of about 7 min. at the highest cooling powers to a maximum of about 22½ min at the lowest cooling power That is to say, the colliers put in 53 minutes of physical work per hour under the most favourable atmospheric conditions, as against 37½ min per hour when the conditions were least favourable. Moreover, their speed of work differed quite appreciably. They took 8·0 min. to fill a tub under the most favourable conditions, as compared with 9·6 min. when they were least favourable. It seems reasonable to assume that if they took 20 per cent more time to fill a tub when the conditions were unfavourable than when they were favourable, they would slow down their rate of hewing coal, of setting props and of doing other work to a similar extent The actual working capacity of the men would therefore be proportional to working time per hour, divided by tub-filling time. Converting the working capacity so assessed into percentages, we see from Table II that under the

TABLE II.—*Working capacity in relation to wet kata cooling power.*

Mean wet kata cooling power	Working time per hr. in min	Tub-filling, time in min	Rate of production
18·6	52·7	8·0	52·7÷8·0=6·59=100
14·6	53·3	8·6	53·3÷8·6=6·20= 94
12·9	51·0	8·5	51·0÷8·5=6·00= 91
10·8	50·0	9·2	50·0÷9 2=5·43= 82
9·0	48·9	9·1	48·9÷9·1=5·37= 81
6·4	37·6	9·6	37·6÷9·6=3·92= 59

most unfavourable atmospheric conditions the working capacity of the men was only 59 per cent. as great as under the most favourable conditions. The results are plotted out in the Figure, and it will be seen that the working capacity fell off at a more and more rapid rate as the wet kata cooling power diminished, the fall being especially rapid when the cooling power dropped from 9·0 to 6·4. This is what we should expect, but at the same time we do not wish to lay stress on the exact numerical measure of the fall. Only six men were observed under the worst conditions, and their involuntary rests from work were much greater than in any of the other groups. In the next two groups, at wet kata

cooling powers of 9·0 and 10·8, the numbers of men observed were 42 and 47 respectively, so these results are more reliable. Arguing from the loss of working capacity then observed, it



Working capacity in relation to wet kata cooling power

seems probable that the loss, under the worst conditions, would be more like 35 per cent. than 41 per cent, but in any case it is very considerable.

It is interesting to note that the wet kata cooling power of 18·6, below which the efficiency of the men deteriorated, closely corresponds to the minimum value of 18 suggested by Hill for good working conditions. It is true that the rest pauses taken did not begin to increase till the wet kata cooling power dropped below 14·6, and the reduction in efficiency depends only on increase of tub-filling time, but the general contour of the curves of working capacity and of tub-filling time suggests that the observed fall is a genuine one. The observations made by Orenstein and Ireland in the Rand gold mine indicate that the work done on a rotary ergometer fell fairly steadily when the wet kata cooling power sank below 15·4, the reduction of efficiency at a cooling power of 6·4 (the minimum observed by us) amounting to 38 per cent.

The other data in Table I indicate that the fall of wet kata cooling power was accompanied by a somewhat similar fall in the dry kata cooling power, and a considerable decrease in the air velocity at the coal face. At the same time the 'effective temperature,' which is discussed in the Appendix, showed a steady rise. The 'sensation of freshness' data, which showed a steady fall, are likewise discussed in the Appendix

It might be maintained that it is not permissible to group together in one scheme the observations made on men working in different seams. As already mentioned, seam C. consisted of hard steam coal, and this necessitated much holing (or undercutting), whereas the soft household coal found in the other seams came away so easily that holing was seldom required. Also, it might be maintained that observations on trammers ought not to be included with those on colliers. We think that these objections have very little weight, and this contention is supported by the data recorded in Table III. These data represent the 77 observations made on colliers only, who were working in the D seam of the two pits. It will be seen that they are fairly well distributed except in respect of the two highest groups of wet kata values, which include only four observations each. Nevertheless, the mean results are in fair agreement with those obtained for colliers and trammers in all of the seams, as can be gathered from the dotted-line curves in the Figure We think that, in spite of their mixed origin, the mean results of the whole observations ought undoubtedly to be accepted as more reliable than those obtained on colliers in the one seam.

It has been stated that the involuntary rests taken by the men were due, for the most part, to a lack of tubs. We made no attempt to ascertain the reasons of this deficiency, but doubtless it was due in part to mechanical causes, though the human element must also have been of importance. The despatch and return of tubs is dependent on the activities of a large number of men working at various points on the haulage roads, and there can be little doubt that high temperatures reduce the energies of these men, but not to the same extent as was observed in the colliers, for the ventilation of the haulage roads is much better than that of the coal face. Still, the haulage men working in the hottest portions of the mine were stripped to the waist, and were streaming with perspiration. Like the colliers, they usually wore cotton knee breeches.

Supposing that by means of an improved system of haulage, and in other ways, it was possible to reduce the time lost involuntarily by lack of tubs and by other causes to zero, the loss of working capacity by the colliers owing to unfavourable atmospheric conditions would still have been very marked. In Table IV we have calculated the rate of production on the assumption that only the voluntary rests counted. The time lost by talking was very small, and was fairly uniform whatever

TABLE III.—*Rest pauses of colliers in D. seam, in relation to wet kata cooling power.*

Range of wet kata cooling power.	Observations.		Rests per hour in minutes.				Tub-filling time in min.	Rate of production	Temperature		Cooling power.		Air vel. in ft per min	Sensation of freshness	Effective temperature.
	Men.	Tubs.	Voluntary.	Involuntary.	Talking.	Total.			Dry bulb.	Wet bulb.	Dry	Wet.			
									°	°					
19 to 16 ..	4	2	4·3	0·2	0·2	4·7	9·0	100	78·8	68·6	5·3	19·2	132	3·0	68·7
15 to 14 ..	4	2	3·8	0·7	1·1	5·6	8·6	103	70·9	65·6	4·7	14·4	32	4·0	66·3
13 to 12 ..	10	7	5·8	3·1	0·6	9·5	8·6	96	80·1	72·2	3·2	12·9	37	3·0	74·1
11 to 10 ..	25	16	5·2	5·4	1·1	11·7	9·7	81	82·5	74·8	2·5	10·6	25	1·7	76·9
9 to 8 ..	29	16	7·4	3·8	0·7	11·9	9·5	82	83·1	76·5	2·3	9·0	18	1·2	78·3
7 to 5 ..	5	3	9·0	11·2	2·2	22·4	9·6	64	85·7	78·7	1·8	6·6	9	0·8	80·7

TABLE IV.—*Working capacity based on voluntary rests.*

Mean wet kata cooling power.	Voluntary rests	Rests in min per hour	Tub-filling time in min	Rate of production.
	min. min			
18·6	4·4 out of possible 57·1	4·6	8·0	55·4÷8·0=6·93=100
14·6	5·0 ,, ,, 58·3	5·1	8·6	54·9÷8·6=6·38= 92
12·9	5·4 ,, ,, 56·4	5·7	8 5	54·3÷8·5=6·39= 92
10·8	5·0 ,, ,, 55·0	5·5	9·2	54·5÷9·2=5·92= 85
9·0	7·3 ,, ,, 56·2	7·8	9·1	52·2÷9·1=5·74= 83
6·4	8·1 ,, ,, 45·7	10 6	9 6	49·4÷9·6=5·15= 74

the atmospheric conditions, so that it may be ignored, and we can say that under the most favourable atmospheric conditions the colliers rested (voluntarily) for 4·4 min. out of a possible 57·1 min. (i e. for 60 min *less* 2·9 min. lost involuntarily and in talking), whilst under the most unfavourable conditions they rested 8·1 min out of a possible 45·7 min. Transmuting these times into rates of production as before, we find that the rate fell off almost as fast as under the previous scheme of calculation, except in the very unfavourable atmospheric conditions. This is well shown by the broken line curve plotted in the Figure.

The Influence of Air Movement on Working Capacity.

The fact that the wet kata cooling power is a good index of atmospheric conditions in relation to working capacity implies that air movement has an important influence, but there is some reason for thinking that it is even more important than cooling power observations would lead one to expect. In order to test its influence, we have taken some of the groups of data which had been sorted out according to their wet kata cooling power, and split them into two fractions, according as the air velocity was low (under 25 ft. per min), or high (over 26 ft. per min.). It will be seen from Table V that by this means we have obtained two similar sized groups of data, in one of which the air velocity averaged 15 ft. per min., and in the other, 51 ft per min. Though the wet kata cooling power of these two groups was practically the same, the rest pauses taken by the low velocity group were 9·6 min. per hour, whilst those taken by the high velocity group were only 7·8 min. Also the tub-filling time was 9·0 min. for the former group as against 8·6 min. for the latter, so the working capacity of the former group came to 8 per cent. less than that of the latter group. Apparently, therefore, in this instance the wet kata cooling power was not an accurate index

TABLE V.—*Rest pauses in relation to air velocity (on basis of wet kata cooling power).*

Conditions.	Range of wet kata cooling power.	Observations.		Rests per hour in minutes.				*Tub-filling time in min.	Temperature.		Cooling power		Air vel in ft. per min	Sensation of freshness	Effective temperature
		Men.	Tubs.	Voluntary	Involuntary.	Talking.	Total.		Dry bulb	Wet bulb	Dry	Wet.			
									°	°					
Low air velocity	15 to 12	16	7	6·4	0·9	0·8	8·1	8·8	69·4	65·6	4·5	14·0	14	3·9	66·6
	11 to 10	28	17	5·6	4·1	1·5	11·2	9 3	78·7	72·8	3 0	10 8	16	2·7	74·6
	Mean	(44)	(24)	6·0	2·5	1·1	9·6	9 0	74·1	69 2	3·8	12·4	15	3·3	70·6
High air velocity	15 to 12	17	10	4·1	2·5	1·0	7·6	8·3	82·4	73·7	3·3	13·5	65	2·7	75·0
	11 to 10	19	11	4·1	3·1	0·9	8·1	9 0	83 8	76 1	2·6	10·8	38	1·9	77·7
	Mean	(36)	(21)	4·1	2·8	0·9	7·8	8·6	83·1	74·9	2·9	12 1	51	2·3	76·3

The difference between the means for the two groups is 0·4 ± 0 2, and may therefore be statistically significant.

of working conditions, as it under-estimated the importance of air movement. However, it was far more accurate than any other available index, such as effective temperature (*cf.* Appendix).

It was not feasible to split up the other wet kata cooling power groups into low velocity and high velocity sections, for only 3 out of the 48 observations made at a cooling power of 9 or less showed an air velocity above 24 ft. per min. Another method of demonstrating the effect of air velocity was to take the wet bulb temperature as the basis of classification, and then sort out the data according to air velocity. There were 53 observations in which the wet bulb temperature ranged from 74° to 76°, and these observations have been split into the five groups recorded in Table VI. The means of the groups show that when the air velocity increased from 13 ft. per min. to 21 ft., the rest pauses taken fell from 12·7 min. per hour to 9·5 min. With greater air velocities there was no further fall in the total rests taken, but the voluntary rests fell a good deal. As is demonstrated in Report No. 41, the involuntary rests are comparatively unimportant, so the *effective* rests were considerably shorter at the highest air velocities.

The influence of air movement on working capacity is suggested by a comparison of the observations made at the two collieries. In Table VII we have grouped the observations made in the two pits according to the wet bulb temperature. Observations at a wet bulb temperature below 71° are not included, owing to paucity of data, but the Table shows the results of 105 out of our total of 138 observations. It will be seen that, on an average, the air velocity at the coal face of pit A came to 22 ft. per min., whilst that at pit B was 35 ft. per min., or 59 per cent. greater The rest pauses at pit B were only 10·1 min. per hour, as compared with 11·8 min. at pit A, and the working capacity of the men was 6 per cent. greater at pit B than at pit A. It is possible of course that this difference may have been due to the operation of other factors in working conditions, but if this conclusion is confirmed by similar evidence obtained at other pits, it will show that even a moderate improvement of atmospheric conditions distinctly increases the earning capacity of the colliers.

So far as we could ascertain, the better ventilation of the coal face at pit B was due entirely to the system of mining adopted. The longwall system was used generally, whilst at pit A it was the exception, and almost all the coal was mined on the pillar and stall system In this system headings, about ten feet in width, are driven into the coal face at intervals, so as to leave a series of pillars which support the roof, and these pillars are removed subsequently. Hence the ventilation is a much more difficult problem than when the whole of the coal is removed at once over a broad face, as in the longwall system. In Table VIII we have classified the air velocities observed by

TABLE VI.—*Effect of changes in air velocity (at wet bulb temperatures of* 74° *to* 76°).

Range of air velocity in ft. per min.	Observations.		Rests per hour in minutes				Tub-filling time in min	Temperature.		Cooling power.		Air vel in ft per min.	Sensation of freshness.	Effective temperature.
	Men	Tubs.	Voluntary.	Involuntary.	Talking.	Total		Dry bulb.	Wet bulb.	Dry	Wet			
								°	°					°
Under 16 ..	10	4	7·5	4·3	0·9	12·7	8·6	81·7	75·3	2·4	8·8	13	2·3	77·1
16 to 19 ..	10	6	7·0	3·2	0·3	10·5	7·9	80·9	75·4	2·7	9·8	17	1·2	76·9
20 to 23 ..	15	7	6·2	2·8	0·5	9·5	9·7	81·2	75·2	2·7	10·6	21	1·9	77·0
27 to 45 ..	9	6	2·8	6·1	0·8	9·7	8·8	82·4	74·9	2·8	10·9	33	1·7	76·6
53 to 121 ..	9	5	4·8	4·0	0·7	9·5	8·0	85·9	76·1	2·6	12·4	71	1·8	77·7

TABLE VII.—*Comparison of rest pauses at the two collieries (on basis of wet bulb temperature).*

	Range of wet bulb temperature.	Observations		Rests per hour in minutes				Tub-filling time in min	Temperature		Cooling power		Air vel in ft per min	Sensation of freshness	Effective temperature.
		Men.	Tubs	Voluntary.	Involuntary	Talking	Total		Dry bulb.	Wet bulb	Dry	Wet			
Colliery A	° 71 to 73	6	3	6·3	0 8	2·9	10·0	9·8	° 77 8	° 72·6	3·4	11·2	24	2·7	° 73·7
	74 to 76	19	9	6 0	4·4	0·6	11·1	8·2	80 9	75·1	2·8	10·5	24	2·1	76·4
	77 to 82	14	7	8·8	4·6	1·1	14·5	9·5	85·1	78·9	2 0	8·2	17	0·7	80·4
	Mean	(39)	(19)	7·0	3·3	1·5	11·8	9·2	81·3	75·5	2·7	10·0	22	1·8	76·8
Colliery B	71 to 73	15	9	4·7	1·5	2·3	8·5	8·9	80·5	73·1	3·1	12·1	38	3·5	74·9
	74 to 76	34	19	5·6	3·6	0·6	9·8	9·0	83·0	75·4	2·6	10·4	32	1·7	77·3
	77 to 82	17	10	5·5	5·2	1·0	11·9	9·1	86·0	78·2	2·1	9·7	35	1·1	79·9
	Mean	(66)	(38)	5·3	3·4	1·3	10·1	9·0	83·2	75·6	2·6	10·7	35	2·1	77·4

TABLE VIII.—*Comparison of air velocities at coal face mined on longwall and on pillar and stall systems.*

Air velocity in feet per min.	Longwall face			Headings and Pillars		
	Colliery A.	Colliery B.	Scotch Collieries	Colliery A.	Colliery B	Scotch Collieries
Total observations	10	36	38	61	8	29
0 to 9	—	1	—	9	—	2
10 to 19	—	7	4	27	5	9
20 to 29	1	11	11	12	3	4
30 to 39	1	4	6	9	—	4
40 to 49	2	1	5	1	—	2
50 to 59	1	2	6	—	—	2
60 to 79	1	4	1	2	—	2
80 to 99	3	2	3	—	—	3
100 or more	1	4	2	1	—	1
Median air velocity	59	28	36	17	17	28
		41			21	

us at the two collieries, according to the system employed. For the reason stated, we were able to make very few observations at longwall faces in colliery A, or at headings and pillars in colliery B, but such as we did make indicate that the air movement was two or three times greater at longwall faces than at faces of headings and pillars. We have also included in Table VIII the observations made by us at three collieries in Scotland (Vernon and Bedford, 1924), and they likewise show a considerably greater velocity at longwall faces. For the three sets of data, the median velocity (or middlemost value of each series) averaged 21 ft. per min. at pillars and headings, and 41 ft. at longwall faces, or practically double. It should be stated that the velocities observed in the Scotch mines have been re-calculated from a new and more accurate table of calibrations (Vernon, 1926). Also they are classified differently from the scheme given in our paper, for there we grouped the pillar observations with those obtained at longwall faces, and not with those at headings.

TABLE IX.—*Air velocity at face in relation to distance of brattice.*

Distance of brattice from face.		Air velocity in intake and return.	Air velocity at face	Per cent of face velocity on velocity in intake and return		Temperature of intake and return		Difference of temperature at face.		
						Dry bulb	Wet bulb	Dry bulb.	Wet bulb.	
ft		*ft. per min.*	*ft. per min*			°F	°F			
3½		166	122	73		72·2	71·0	+0·3	−0·2	
4		8	5	63		86·7	78·1	+0·4	+1·7	
5	5½	26	24	92	68	82·8	79·8	+0·2	−0·4	+0·3
6		130	68	52		72·8	71·7	+0·2	−0·2	
7		14	9	64		88·4	81·0	+0·2	+1·0	
8		68	44	65		60·4	56·0	−0·2	0·0	
12	12	76	31	41	47	66·6	64·4	0·0	+0·5	+0·8
12½		31	16	52		83·9	73·1	+0·5	+1·0	
15		28	7	25		72·4	67·7	+0·6	+2·5	
20	31	37	15	41	32	70·6	69·9	+1·2	+1·6	+2·2
33		46	20	43		69·1	68·7	+0·3	+0·3	
55		42	8	19		74·1	69·1	+2·3	+4·5	

An important factor in determining the air velocity at the coal face in headings, where it is usually lower even than that at pillar faces, is the distance between the brattice, or partition fixed between the intake and return airways, and the working face. In Table IX are collected the observations made by us in the Scotch collieries and in collieries A and B, and it will be seen that in various instances the distance of the brattice cloth from the face varied between the extremes of 3½ ft and 55 ft. We determined the velocity of the air current in the intake and return airways, as well as at the face, and it will be seen from the Table that when the brattice was 8 ft. or less from the face, the air movement was nearly 70 per cent as great as the average observed in the intake and return When, however, it was distant 15 ft. or more, the air current reaching the face sank to about a third, and, indeed, when it was 55 ft. distant it sank to a fifth. This reduction in air velocity was accompanied by an increase in temperature, for we see from the Table that when the brattice was 15 ft. or more away, the wet bulb temperature at the face was 2·2° higher than in the intake and return, whilst it was only 0·3° higher when the brattice was 8 ft. or less away.

It would appear, therefore, that the advance of the brattice as far as is compatible with safety in shot-firing, will often have a favourable influence on the comfort and efficiency of the men, though occasionally, when the air velocity in the intake and return airways is considerable, it may be advisable not to advance the brattice to the shortest distance, as a continuous draught blowing on the bare backs of the colliers may give them rheumatism.

The Influence of Atmospheric Conditions on Accidents.

There is reason for thinking that the number of accidents incurred may be influenced a good deal by the atmospheric conditions under which the miners are at work Thus Davies (1922) found that when a cooling plant was introduced at the Morro Velho gold mine in Brazil, by means of which the intake air was cooled from about 67° down to 43°, the wet bulb temperature in the deepest workings—some 6,000 ft. below the surface—was reduced from 89° to 80°. That is to say, the almost insupportable conditions became quite bearable , and the improvement was reflected in the accident rate. In the 16 months previous to the installation of the plant there were 20 fatal accidents, and in the 16 months after its introduction, only 6. Under the cooler conditions the men were presumably more alert to perceive and to avoid danger, and more ready to take precautions. Again, one of us, working in conjunction with Mrs. Osborne, (1922), found that the liability of munition workers to minor accidents was greatly influenced by temperature. We recorded the temperature in three large munition factories continuously for a period of six to twelve months, and at the same time deter-

mined the number of cuts (which formed over 70 per cent. of all the accidents) treated at the ambulance rooms. We found that these accidents reached a minimum at a temperature of 67° (dry bulb), and at 77° they were 39 per cent. more numerous in the men. Further evidence relating to the influence of atmospheric conditions on accident rates is obtainable from the comparative mortality figures supplied by the Registrar-General, but the discussion of these figures falls more conveniently in a later section of this report (p. 21).

The accident data at our disposal consisted of a record of all accidents on which compensation was paid for many years back, but we thought it useless to investigate them earlier than 1920, because of the upsetting effect of war and post-war conditions. From 1920 to 1923 all accidents involving an absence from work of over seven days were compensated, whilst from 1924 onwards the minimum time was reduced to over three days. In the period investigated there were 2,459 accidents altogether, and they were incurred by 2,963 men. We were able to obtain information concerning the number of shifts worked, and could thereby calculate the accident frequency per 100,000 man-shifts per year. We also calculated the *severity rates* of the accidents, i.e., the accidents in terms of the number of days lost per 1,000 hours worked. It was assumed that the shifts lasted 7½ hours, as this is approximately the time the men are underground. A difficulty arose in regard to fatal accidents, for in some schemes it is customary to regard each such accident as equivalent to the loss of 20 years, or 20 × 300 = 6,000 working days. At one of the collieries investigated by us the number of fatal accidents varied from 0 to 4 in successive years, whilst in the other one it varied from 0 to 3. In consequence, the annual severity rates were extremely irregular when 6,000 days were allowed for each fatality, so we thought it best to re-calculate all our severity rates on another basis, according to which no accident, either fatal or otherwise, was considered to cause a loss of more than 150 days (or 6 months) of working time. Our choice of 6 months as the limit was arbitrary, but we considered that the differences in the circumstances which caused a six-month disability or a fatal accident were usually so small that it was almost a matter of chance which event happened. The modified severity rates so calculated are comparatively regular from year to year.

We were able to ascertain the accident rate at two seams (D. and F.) of colliery B, whilst at colliery A we obtained separate data for the upper and lower portions of the D. seam, as well as for the C. seam. When planning our scheme of work, we endeavoured to select working places distributed fairly evenly over the various seams, so that we might be able to get a fair idea of the average atmospheric conditions at the coal face ; but our method was necessarily rather a rough one. The mean atmospheric conditions observed are recorded in Table X, and it will be seen that in the different seams the dry bulb temperature varied

between the extremes of 64·6° and 85·4°. The wet kata cooling power showed less variation, as it ranged only from 15·2 to 10·2. In the lower half of the Table are recorded the accident severity and accident frequency rates in the various seams, as experienced by some of the classified groups of men during the six-year period, 1920–25, and by the whole body of underground workers during the four years 1922–25. The complete data could not be obtained for the years 1920–21, owing to some of the man-shift figures being mislaid. It will be seen that the accident frequency was much greater at colliery B than at colliery A, whilst the severity rate showed only a moderate excess. On an average (for 1922–25), all the workers showed an excess of 69 per cent. in frequency, whilst the colliers and trammers (for 1920–25), showed an excess of 49 per cent. The severity rate showed an excess of 20 and 10 per cent. respectively, or a third to a fifth as much. The difference in the two rates was due almost entirely to the larger number of minor accidents at colliery B This was partly the result of differences in local conditions, for the accidents to the haulage hands and road repair men, which were of a less severe type than the accidents to the face workers (*cf.* Table X), were relatively more numerous at colliery B than at colliery A (*cf.* Table XI)

If any relationship exists between accident rates and the differences of atmospheric conditions observed by us, we should expect to find it shown most clearly in the colliers and trammers, for they worked at the coal face where the atmospheric conditions were investigated At colliery A, there was, in fact, a fairly close parallel between the accident rate and the wet kata cooling power, for the cooling powers in the three seams, or parts of seams, averaged 15·2, 11·3, and 10·2, whilst the corresponding severity rates were respectively 3·2, 4·8 and 4·9, and the frequency rates, 57, 80 and 84. At colliery B the slight variations observed in cooling power and in the severity and frequency rates likewise corresponded. If we group together all the results obtained in the two mines, we find that in four of the seams the cooling power was fairly steady, as it ranged only from 10·2 to 12·5, and at the same time the accident severity rate was fairly steady, as it ranged from 4·5 to 5·0. In one seam only did the cooling power of 15·2 differ somewhat widely from that observed in the other seams, and the accident severity rate of 3·2 observed in this seam likewise differed widely from the rest. Hence the data obtained support the view that atmospheric conditions influence the accident rate ; but it is evident that, in order to get a really satisfactory proof, it will be necessary to obtain, not only a much larger body of information, but information relating to a wider range of atmospheric conditions.

No mention has been made of the condition of the roof of the various seams, though this must necessarily influence the accident rate. It was extremely difficult to obtain any idea of the comparative risks run, but as the result of information derived from the

TABLE X.—*Accident severity and frequency in relation to atmospheric conditions.*

		Accident severity, etc					Accidents per 100,000 man-shifts.				
		Colliery A.			Colliery B.		Colliery A.			Colliery B.	
		Seam C.	Seam D (upper.)	Seam D (lower.)	Seam D	Seam F.	Seam C.	Seam D (upper)	Seam D. (lower.)	Seam D.	Seam F.
Atmospheric conditions at face.	Dry bulb temperature	64·6°	77·3°	81·4°	83·4°	85·4°					
	Wet ,, ,,	62·2	71·6	76·2	74·8	75·7	—	—	—	—	—
	Dry kata cooling power	5·7	3·4	2·7	2 6	2 6	—	—	—	—	—
	Wet ,, ,, ,,	15·2	11·3	10·2	11 1	12 5	—	—	—	—	—
Accidents to Underground workers	Colliers and trammers (1920–25.)	3·2	4·8	4·9	5 0	4·5	57	80	84	116	104
	Haulage men and boys (1920–25)	1·5	1·7	1·5	—	—	36	37	33	—	—
	All others (1920–25) ..	2·1	2·0	1·3	—	—	26	28	29	—	—
	All workers (1922–25)..	2·9	3·5	3·1	3·4	4·2	53	63	59	91	106
Depth of workings below surface, in ft.		616	1,359	1,778	1,942	2,168	—	—	—	—	—
Average number of men and boys work-working in seam (1920-1925).		649	506	498	910	400	—	—	—	—	—

management and from our own observations, we concluded that the F. seam at colliery B had the worst roof, whilst the C. seam at colliery A came next. However, the men in these seams knew that they had a bad roof, and were on the alert, whilst the roof of the D. seam, though to all appearances in a much better state, was apt to fall in without giving any warning. There was more trouble from falls of " clod " at colliery B than at colliery A.

The severity rates recorded in Table X for haulage men and for other underground workers—mostly repair men—show no sort of relationship to the cooling power of the air, and they would scarcely be expected to do so. These men were for the most part working in the airways of the mines, where the temperature is lower than at the face, and where there is almost always a very considerable degree of air movement. We did not make any direct measurements of air velocity, but our bodily sensations told us quite enough. We noted that the air currents in the airways of mine A were quite definitely more rapid than those at mine B, whilst, as we pointed out previously, the reverse relationship held at the coal face, the mean air velocity in mine B being 59 per cent. greater than in mine A. These differences of air movement are probably responsible, at least in part, for the fact that whilst the accident severity rate of the face workers at colliery B was only 4 per cent. greater than at colliery A, that of all the other underground workers was 55 per cent. greater. The actual rates observed in the various seams, in respect of frequency as well as of severity, are recorded in Table XI.

TABLE XI.—*Accident rate per* 100,000 *man-shifts* (1922–25).

		Colliery A				Colliery B			Per cent. excess at B
		Seam C	Seam D (upper)	Seam D (lower)	Mean	Seam D	Seam F	Mean	
Severity rate	Colliers and trammers	3 9	5·4	5 0	4·8	5 2	4 8	5·0	4
	All other underground workers	1 8	2 0	1 7	1 8	2 1	3·4	2·8	55
Frequency	Colliers and trammers	65	93	92	83	127	115	121	46
	All other underground workers.	38	38	37	38	64	95	80	111

The Influence of Atmospheric Conditions on the General Health of Coal Miners.

We did not obtain any direct information about the influence of atmospheric conditions on the health of miners apart from their liability to accidents, but indirect evidence exists which suggests that this influence is considerable. The mortality statistics compiled by the Registrar-General show that in the most recent period available, viz., 1910 to 1912, the comparative mortality figure (for men aged 25 to 65) ranged from a lower limit of 570 for coal miners in Nottinghamshire to an upper limit of 941 for those in Lancashire. Part of this difference is probably due to local

TABLE XII.—*Comparative mortality of coal miners,* 1910–12

District.	Relative death rate of male population	Comparative mortality from							As a percentage on comparative mortality.										Mean depth of mines in ft.	
		All causes.		Phthisis.	Pneumonia.	Bronchitis.	Accidents.	Othercauses.	Phthisis		Pneumonia.		Bronchitis.		Accidents.		Other causes.			
Nottinghamshire . .	100	570		53	40	25	66	386	9·3		7·0		4·4		11·6		68		1,220	
Derbyshire . .	94	591	599	70	34	39	73	375	11·8	10·7	5·8	7·1	6 6	5·4	12·4	12 4	63	64	920	913
Northumberland and Durham	113	635		70	54	33	83	395	11·0		8·5		5·2		13·1		62		600	
Staffordshire . .	108	717		74	70	61	109	403	10·3		9·8		8·5		15·2		56		—	
Yorkshire	111	758		81	69	45	117	446	10·7		9·1		5·9		15·4		59		1,220	
Monmouth and South Wales	106	777	825	70	69	66	131	441	9·0	10·4	8·9	9·5	8·5	7·9	16·9	17·2	57	55	1,650	1457
Lancashire . .	125	941		107	100	88	183	463	11·4		10·6		9·4		19·4		49		1,500	
Per cent. difference between high and low mortality groups	—	—		—	—	—	—	—	−3		+34		+46		+39		−14			

differences of climate and other conditions, for the figures recorded in the second column of Table XII show that the death rate of the general male population in the various counties, relative to that in Nottinghamshire taken as 100, varied from 94 to 125. These data, which are derived from statistics recorded by Collis (1922), relate to the years 1901 to 1910, but they are sufficiently near for our purpose, and they indicate a slight rise in mortality which runs more or less parallel with the considerable rise shown by the miners.

It will be seen from Table XII that the rise in the miners' mortality was due chiefly to respiratory diseases and to accidents, whilst the rise from "other causes" was comparatively small. In the right half of the Table the mortalities from various causes have been calculated as percentages on their respective comparative mortality figures, and it will be seen that when reckoned in this way the mortality from phthisis remained steady at about 10 per cent. in all coal fields On the other hand, the mortalities from pneumonia and bronchitis rose more rapidly than the comparative mortalities, and were nearly double as great in Lancashire as in Derbyshire or Nottinghamshire. The accident mortality varied in similar fashion, and if we split all the data into two groups (from which those obtained in Staffordshire are omitted, for the reason stated below), we find that on an average the high mortality group, as compared with the low one, showed a 34 per cent. excess of deaths in respect of pneumonia, a 46 per cent. excess in respect of bronchitis, and a 39 per cent excess in respect of accidents. There is reason for thinking that this parallel rise is due in part, at least, to the more adverse atmospheric conditions usually met with in the high mortality group of coal mines. Information obtained from the Mines Department (*cf.* Collis, *l. c.*) shows that on an average the high mortality group of mines were 544 ft. deeper than the other group (the average depth of the Staffordshire mines being uncertain) As the rise of temperature is about 1° F. for every increase of 60 ft in depth, this means that they were about 9° hotter than the others. Judging from our own results, the miners would be working at a temperature of about 80° instead of at 70°, and they would therefore tend to suffer a greater rise of body temperature, and to perspire more freely. On returning to the surface, they would be more liable to catch chills, and to suffer from pneumonia and bronchitis. As has been suggested in the previous section, the higher temperatures experienced underground would tend to increase accident frequency, owing to their psychological effect on attention.

It must be admitted that, so far as can be deduced from the data in Table XII, the relationship between depth of mine and mortality from respiratory diseases and from accidents does not appear to be a very close one. The Nottinghamshire data are specially contradictory, but taking the results as a whole, the correspondence is good enough to afford *prima facie* support to our main contention, and to encourage us to collect more exact

information about the accident frequency of individual mines, in relation to depth and to atmospheric conditions. If such information gives substantial support to our contention, we may be justified in formulating a general principle to the effect that "the more adverse the atmospheric conditions experienced underground, the greater the reduction in the health and efficiency of the miners, and the greater their tendency to incur accidents." Such a principle is supported by a certain amount of evidence from other industries, and its establishment is so important that we think it worth while to recapitulate this evidence briefly

The influence of atmospheric conditions on health has been investigated by us in several factories (Vernon and Bedford, 1926). At a tin canister factory, the time lost by sickness was determined for 809 women over a period of two years, and in a workroom where the mean temperature was 7° above the average, owing to the presence of drying stoves, the time lost by sickness was 32 per cent. greater than in the other rooms. At another factory, two groups of women, 81 and 54 in number, were engaged on the same light repetition work in different rooms, and in one of them the mean air velocity was only half as great as in the other. The women in this room were found, over a two-year period, to lose 53 per cent. more time from sickness than the others. Parallel evidence, indicating that even a slight rise in the mean temperature of schoolrooms above 66° considerably increased the sickness experienced by school children, has been collected on a very large scale in America, but it is not described here as it does not relate to industrial workers.

The influence of atmospheric conditions on the efficiency of workers in heavy trades has been studied in some detail. At the Morro Velho gold mine previously referred to, Davies (1922) found that the output from the mine went up 12 per cent. after the cooling plant was installed. In tin plate factories, one of us (Vernon, 1919) collected output data of the millmen for periods of 1½ to 7 years, and found that the output was at a maximum in the winter months, when it was coldest, and steadily fell to a minimum in the hottest part of the summer. In a factory where a good artificial ventilation was installed, the summer fall of output amounted only to 3 per cent., whilst in one with a moderately good ventilation it was 6·4 per cent. On the other hand, two factories without any artificial ventilation showed a fall of 11·0 and 13·4 per cent. respectively. Again, the output of the open hearth steel melters and the rolling mill men at various steel works was found to be at a minimum in the summer, the reduction in the steel ingots produced at one works being 11 per cent. on the winter output, whilst that of rolled steel at another works was 10 per cent. At the puddling furnaces, the men produced 8 per cent. less wrought iron in the summer than in the winter (Vernon, 1920). A reduction of output during the summer months has likewise been observed by Farmer (1924) in the glass trade.

To return to the comparative mortality data, the increase of phthisis mortality noted in the deeper mines may be due to geological causes. Indeed, Collis suggests that the increase of all the respiratory diseases may be due to the silica content of the coal worked, and of the roof. However, this explanation does not appear to account for the exceptional rise in the pneumonia and bronchitis mortality, as compared with that from phthisis.

Summary.

The influence of atmospheric conditions on the working capacity of colliers can conveniently be measured by noting down (*a*) the rest pauses taken from work, and (*b*) the time taken to fill the tubs 138 men were watched for an average period of 96 minutes each, and in air with a wet kata cooling power of 19 to 14 they were found to rest 7 minutes per hour, whilst in air with a cooling power of 7 to 5 they rested 22 minutes. Tub-filling took 8·0 minutes under the former conditions and 9·6 minutes under the latter, and the rate of production of the men was calculated to be 41 per cent. less under the most adverse atmospheric conditions than under the most favourable ones.

The rest pauses taken were partly voluntary and partly involuntary (due chiefly to the lack of tubs). If, however, regard is paid only to the voluntary rests taken during such time as work is possible, the effect of atmospheric conditions still proves to be very marked, though not so great as when all the rests are taken into account.

The average air velocity at pillars and headings was only half that observed at longwall faces, but it can be greatly increased in headings by keeping the brattice well advanced. When the brattice was 5½ ft. distant from the face the velocity was 68 per cent as great as that observed in the intake and return airways; but when 31 ft distant, it was only 32 per cent. as great.

The accident rate appears to be influenced by atmospheric conditions, for at one colliery, where the wet kata cooling power in three seams was 15·2, 11 3 and 10·2, the (modified) accident severity rate of the colliers and trammers was 3·2, 4·8 and 4·9 respectively Also at one colliery, where the ventilation in the airways was worse than in the other, the accident severity rate to underground workers (other than colliers and trammers) was 55 per cent greater than in the other colliery At the coal face, however, where the ventilation in the first of these collieries was better than in the second, the severity rate of the colliers and trammers was only 4 per cent in excess. The accident frequency varied in the same way as the severity rate.

There is reason for thinking that the more adverse the atmospheric conditions experienced underground, the greater the reduction in the health of the miners

In conclusion, we wish to offer our warm thanks to the management of the two collieries visited by us, for their kind assistance during our investigation. This frequently entailed the expenditure of a great deal of time and labour on their part.

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APPENDIX.

Working Capacity in relation to Effective Temperature.

As already stated, the wet kata cooling power depends only on the wet bulb temperature and the air velocity, so it is important to determine as definitely as we can whether the dry bulb temperature is entirely without influence on working capacity, except in so far as it affects the wet bulb temperature in the manner previously pointed out. An index of comfort which includes a dry bulb temperature factor as well as wet bulb and air velocity factors has recently been determined in America, as the result of a large number of investigations in the laboratory of the American Society of Heating and Ventilating Engineers, Pittsburgh It is termed the "effective temperature," and it was determined by making observations in two adjoining rooms, the temperature, humidity and air movement in which could be controlled independently (Houghten, Yagloglou, and others) * The subjects of experiment, three in number, passed backwards and forwards from one chamber to the other, and various combinations of temperature, humidity and air velocity were induced such as produced equal degrees of comfort, or of discomfort In one series of observations the subjects were stripped to the waist, and were therefore roughly comparable, as regards clothing, to the miners investigated by us A chart was constructed from which any combination of wet and dry bulb temperature up to 110° F., and of air velocity up to 700 ft. per min, could be transmuted into terms of effective temperature, and we have used this chart for the conversion of all our data These data have been split up into five groups, according to the effective temperature, and the averages are recorded in Table XIII It will be seen that at the lowest effective temperatures the total rests taken averaged 7 to 8 minutes per hour, whilst at the highest effective temperatures they rose to 13·4 minutes

The range of variation in rest pauses was much smaller than when wet kata cooling power was the basis, for the extremes varied as 1 to 1·9, whilst they varied as 1 to 3·3 on the wet kata cooling power basis The tub-filling time showed no definite relation to the effective temperature, and on calculating the correlation co-efficient between effective temperature (distributed in the five groups shown in Table XIII) and the 75 tub-filling times ascertained by us, we obtained the value $0 \cdot 109 \pm 0 \cdot 077$ That is to say, the co-efficient was only slightly larger than the probable error, and therefore it cannot be regarded as significant The correlation co-efficient between wet kata cooling power and tub-filling time came to $-0 \cdot 223 \pm 0 \cdot 074$, and as this co-efficient is more than three times larger than the probable error, it may be accepted as significant It is negative because tub-filling time increased as the wet kata cooling power diminished, whilst the other co-efficient is positive, because the tub-filling time tended to increase slightly with the effective temperature

The working capacity of the men, in relation to effective temperature, has been calculated on the principle previously described, and is recorded in Table XIII It will be seen that at the highest effective temperatures it fell only 10 to 15 per cent below that observed at the lowest temperature, whilst it will be remembered that when wet kata cooling power was the basis of classification, it fell 41 per cent. (at the lowest cooling power). However, the less marked relationship of effective temperature to working capacity may be due to its dry bulb temperature factor being over represented, and it does not prove that the dry bulb temperature ought not to be allowed for at all In order to obtain further information on the question, we have re-classified our data in another way. Taking all the data with a

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* Houghten, F C., Yagloglou, C.P, Miller, W. E, and McConnell, W. J. (1923 to 1925). Numerous papers in *Journ Amer. Soc. Heating and Vent. Eng* See also Yaglou, C. P. (1926). *Journ Indust Hyg* **8.** 5.

TABLE XIII.—*Rest pauses and workıng capacity ın relatıon to effectıve temperature.*

Range of Effective temperature.	Number of observa- tıons.	Rests per hour in mınutes. Volun- tary	Invol- untary	Talk- ing	Total.	Tub fillıng tıme in min.	Rate of pro- ductıon	Temperature. Dry bulb.	Wet bulb.	Cooling power Dry.	Wet.	Air velocıty ın ft. per mın	Sensation of freshness.	Effectıve tempera- ture
Under 68° ..	17	5·9	1·3	0·8	8·0	8·4	100	64·5°	62·2°	5·7	15·2	18	4·8	62·1°
68° to 71° ..	10	3·2	3·3	0·5	7·0	9·3	92	77·2	68·6	4·5	15·6	73	3·2	69·5
72° to 75° ..	41	5·5	1·9	1·5	8·9	8·8	94	78·7	73·2	3·3	11·4	27	3·0	74·4
76° to 79° ..	54	6·3	4·4	0·8	11·5	9·2	85	83·9	76·0	2·4	10·1	30	1·5	78·0
80° or more ..	16	6·7	5·4	1·3	13·4	8·4	90	87 3	79·5	1·8	8·5	27	0·7	81·3

TABLE XIV—*The Influence of effectıve temperature (on basıs of wet kata cooling power).*

Condıtıons.	Range of wet kata coolıng power.	Number of observa- tıons	Rests per hour ın mınutes Volun- tary	Invol- untary	Talk- ıng	Total	Tub fillıng tıme ın mın	Temperature Dry bulb.	Wet bulb	Coolıng power Dry	Wet	Air velocity ın ft per mın.	Sensation of freshness.	Effective tempera- ture.
Low effectıve temperature	15 to 12	17	5·4	1 1	1·0	7·5	8·7	69·2°	64 6°	4·8	14·1	20	3·9	65·7°
	11 to 10	26	5 3	3 1	1·4	9·8	9·1	76 9	72 3	3 4	10·9	19	3·1	73·4
	9 to 8	16	6·6	2 4	0 9	9·9	8·1	78 9	74·3	2·9	9·2	15	2·6	75·6
	Mean	(59)	5·8	2·2	1·1	9·1	8·6	75·0	70·4	3·7	11·4	18	3·2	71·6
Hıgh effectıve temperature	15 to 12	16	5 0	2·4	0·9	8·3	8·4	83·4	75·2	3·0	13·4	61	2·6	76·4
	11 to 10	21	4·6	4·4	1·0	10·0	9·2	85·7	76·3	2·1	10·6	32	1·5	78·8
	9 to 8	26	7·7	3·6	0 6	11·9	9·4	84·5	77·3	2 1	8 8	19	0·7	79·2
	Mean.	(63)	5·8	3 5	0·8	10 1	9·0	84·5	76·3	2·4	10·9	37	1·6	78·1

wet kata cooling power of 15 to 12, we have sorted them out into two nearly equal parts, according as they had a relatively low or a relatively high effective temperature. We have done the same thing with the data having a cooling power of 11 to 10, and with those having one of 9 to 8 The other data had to be ignored, because they were so few in number, but it will be seen from Table XIV that we have classified 122 observations out of our total of 138. Taking means of the two groups, we see that, on an average, one group had an effective temperature which was 6·5° higher than that of the other group Its total rest pause time was 10·1 minutes as against 9·1 minutes, but the voluntary rests were just the same in both instances, and the excess is due to longer involuntary rests As is shown in Report No 41, involuntary rests are of very much less significance than voluntary rests, so the *effective* rests were almost the same in both sets of data. This was owing to the wet kata cooling power being almost the same, in spite of the great difference in effective temperature This difference was due chiefly to the dry bulb temperature being 9·5° higher in the one group of data than in the other The wet bulb temperature was 5·9° higher, but its influence was neutralised by the greater air velocity Hence we are probably justified in concluding that the high dry bulb temperature had practically no effect on working capacity, either favourable or unfavourable, though the evidence is not absolutely clear

The apparent contradiction between our observations and those made in the Pittsburgh laboratory is due to the fact that our subjects of experiment, the colliers, were doing such heavy work that they were almost invariably streaming with perspiration, and in consequence they reacted only to the wet bulb temperature The subjects at Pittsburgh were doing only the light work necessitated by moving from one experimental chamber to the other, and therefore they would be perspiring but little, except at very high temperatures Information tending to support the correctness of effective temperature as an index of comfort when the subjects are resting or doing very light work, was obtained by us in an indirect manner After we had been sitting at rest in a working place for an hour or more, we noted down our sensations of the atmospheric conditions We used the following scale, to which, for convenience in tabulation, we assigned the marks 0 to 8.

Atmospheric conditions felt to be	*Marks assigned.*
Very oppressive	0
Distinctly ,,	1
Rather ,,	2
Slightly ,,	3
Medium	4
Slightly fresh	5
Rather ,,	6
Distinctly ,,	7
Very ,,	8

In the course of our observations, we experienced a sensation of 0 or 1 on 27 per cent. of all occasions, one of 2 or 3 on 53 per cent. of all occasions, and one of 4 to 6 on 20 per cent. of all occasions The 7 and 8 sensations were never experienced in the working places, though frequently in the haulage roads.

It will be seen from Table XIV that in the high effective temperature group of observations the mean "sensation of freshness" experienced was 1·6, or something worse than "rather oppressive." In the low effective temperature group, however, the sensation experienced was 3·2, or something rather better than "slightly oppressive." That is to say, we ourselves, because we were doing no muscular work to speak of and were not perspiring like the colliers, reacted more or less in proportion to the effective temperature of the air Further evidence showing the unreliability of effective

TABLE XV.—*Rest pauses and working capacity in relation to dry kata cooling power.*

Range of dry kata cooling power.	Number of observations	Rests per hour in minutes				Tub filling time in min	Rate of production	Temperature		Cooling power		Air velocity in ft per min.	Sensation of freshness.	Effective temperature.
		Voluntary	Involuntary	Talking	Total			Dry bulb.	Wet bulb.	Dry	Wet			
7·9 to 7·0 ..	4	4·8	3·1	0·4	8·3	7·4	100	63·0°	60·1°	7 0	18 6	36	6·0	58·7°
5·9 to 5·0 ..	15	5·9	0 5	0 8	7 2	8·9	85	68·7	64 4	5·3	15·5	44	4·1	64·0
4·9 to 4·0 ..	6	3·8	1·3	1 0	6·1	8·3	93	72·5	66 4	4·5	13·9	33	3·7	67·7
3·9 to 3·0 ..	44	5·0	2 4	1·3	8·7	8·7	84	78·8	73·2	3·3	11·6	31	2·9	74·4
2·9 to 2·0 ..	54	6·3	3·9	0·9	11·1	9·5	74	83·8	76·2	2·3	10 0	29	1·6	78·1
1·9 to 1·0 ..	15	7 6	7·5	1·2	16·3	8·3	75	87·3	78·7	1·6	8·3	17	0·5	81·1

temperature is afforded by the results recorded in Table V. These data indicate that in air currents of high velocity the rest pauses taken were considerably shorter than in air currents of low velocity, in spite of the fact that the effective temperature was 5·7° higher As might have been expected, the sensation of freshness experienced by the investigators ran parallel to the effective temperature, and not to the wet kata cooling power, or the working capacity of the miners.

In Table XV the data have been classified on the basis of *dry* kata cooling power, and it will be seen that the rest pauses taken by the men at various dry kata cooling powers varied from 6·1 minutes per hour to 16·3 minutes. The tub-filling time showed no consistent relationship to cooling power, but the working capacity, when calculated by the method previously described, showed a fairly rapid and fairly regular fall as the cooling power diminished. At the lowest cooling powers the loss of efficiency amounted to 25–26 per cent , or much more than the loss exhibited at the highest effective temperatures. Hence the dry kata cooling power appears to afford a better index of the suitability of atmospheric conditions for hard muscular work than that given by effective temperature. Probably this is because it makes a much larger allowance for the air velocity factor than effective temperature does (*cf.* Vernon and Bedford*).

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* Vernon, H. M., and Bedford, T. (1926). "The Influence of Cooling Power and of Variability of Air Currents on Sensations of Air Movements." *Med. Res. Council Special Report, No. 100.*

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MEDICAL RESEARCH COUNCIL.

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REPORT No. 40.

The Effect of Eyestrain on the Output of Linkers in the Hosiery Industry.

By H. C. WESTON, M. J. Inst.E., and S. ADAMS, M.Sc.

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PREFACE.

Many industrial processes demand for their effective performance the clear perception of fine detail, and some evidence already exists that continuous work of this nature tends to have a deleterious effect upon eyesight. Thus, a special examination of the history of 480 myopic subjects revealed the fact that whereas of those who had not been engaged on fine processes, 9·4 per cent. had failed owing to visual troubles at some time during their occupations, and of these 7 per cent. sustained definite damage to their eyes, of those who had been engaged in occupations involving habitual close eye-work, such as sewing, the corresponding numbers rose to 53 per cent and 15 per cent.* It becomes important therefore to consider the visual factors involved in such processes

The perception of fine detail depends upon the operation within limits of two factors, the size of the retinal image and the illumination on the object viewed , that is to say, the eye must be so placed relatively to the object that the retinal image is large enough to allow of adequate discrimination of the details, whilst the necessary size of image depends in turn upon the illumination, which as it rises increases the contrast between the elements of the detail, so that the eye is satisfied with a relatively smaller retinal image. When the illumination is too low, then, the only resource available is to increase the size of the retinal image by diminishing the distance between the eye and the object, with the result that continuous strain is imposed to a greater or less extent on the muscles of accommodation and convergence. It follows that the first requirement for fine industrial processes is good lighting, namely an adequate illumination and suitable arrangement of light sources, and it has in fact been shown that output in such processes can be notably increased by increasing the illumination.†

In certain extreme cases, however, the details are so exceptionally fine, that illumination, however high, does not wholly eliminate the necessity of near vision with its concomitant disadvantages of excessive accommodation and convergence. Relief of the eyestrain involved can then only be secured by replacing the excessive accommodation and convergence by the use of suitable lenses and prisms respectively.

The present report describes a preliminary attempt to apply this method under practical conditions. The enquiry was initiated in the following circumstances. In 1923, the Home Office Departmental Committee on Factory Lighting issued a third and final report,‡ dealing specially with the lighting required for fine purposes, to which were appended two schedules, one enumerating

* Departmental Committee on the Causes and Prevention of Blindness Final Report, 1922, p 53 —*H M Stationery Office.*

† A summary of the results obtained is given in the Sixth Annual Report of the Board. p. 72 —*H M Stationery Office.*

‡ Cmd. 1686 (1922).

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so called "fine" industrial processes, and the other "very fine" processes. Whilst provisional standards of 3 and 5 foot-candles respectively were suggested for these groups, it was pointed out at the same time that much further research was called for before the minimum illumination desirable for any given process could be regarded as definitely established. As an initial step, the Home Office accordingly selected a few of the processes which appeared to call specially for investigation and referred them with this object to the Illumination Research Committee of the Department of Scientific and Industrial Research. Amongst the processes named were "hand composing" in letter-press printing, and "linking" in hosiery.

The former appeared to be a process in which adequate and suitable lighting alone was called for, and accordingly an investigation was carried out by the Illumination Research Committee and the Board jointly. The results, which have recently been published, indicate that output may increase (and errors diminish) with illumination, up to a limiting value far higher than that commonly found in composing rooms.*

A preliminary inquiry into "linking," however, suggested that the problem would not be entirely solved by high illumination and that visual aids of the kind already described were called for. The matter was accordingly referred to the Committee on Physiology of Vision of the Medical Research Council, under whose supervision the present investigation has been carried out. Inasmuch, however, as its interest appeared to be predominantly industrial, it has been decided to publish the report as one of the series of the Industrial Fatigue Research Board.

Since the investigation was intended merely as a preliminary test of the effect of the method adopted (the use of special spectacles), it was thought desirable to avoid any minute refinement in fitting the spectacles, and, in order to encourage the wearing of them, to leave a great deal to the choice of the individual subjects, as is recorded in Appendix II Nevertheless, even with this limitation the results, relating to three operatives over a period of four weeks, are consistent in showing that an increase in the rate of working has followed their use.

Research is being extended to other very fine processes, a standardised method of prescribing the necessary spectacles being employed.

The Board and the Committee desire to acknowledge with thanks the valuable help given by Mr. W. B. Laws, M.B , F.R.C.S., of Nottingham, by whom the eyesight of the subjects concerned was examined, and also to express their indebtedness to Messrs J. B. Lewis & Sons Ltd., of Nottingham for the experimental facilities afforded.

December, 1926.

* The Relation between Illumination and Efficiency in Fine Work (Typesetting by hand). (Joint Report of the Industrial Fatigue Research Board and Illumination Research Committee) —*H.M. Stationery Office*.

THE EFFECT OF EYESTRAIN ON THE OUTPUT OF LINKERS IN THE HOSIERY INDUSTRY.

By H. C. WESTON, M.J. Inst.E., and S. ADAMS, M.Sc.
Investigators to the Board.

CONTENTS.

Introduction.

Many industrial occupations involving close and constant visual inspection may impose strain upon the eyes of those engaged in their performance, if the illumination provided is insufficient to make clear the detail to be observed. Even, however, if the best illumination is provided, eyestrain cannot be avoided entirely, when the nature of the work is such that extreme accommodation and convergence of the eyes are necessary in order to see very small details. Strain can then only be relieved if the refractive power of the eyes is increased by means of suitable glasses, thus allowing a clear image to be formed upon the retina with less effort of accommodation than would normally be required. In the case of the watchmaker the maximum accommodative power of the eye is insufficient to enable him to see all the fine detail of his work, which has therefore to be magnified by means of the familiar watchmaker's glass. The details of other kinds of work, though not so small, may be difficult to distinguish, unless viewed at very close quarters, owing to absence of contrast. This is so in the process of linking, but whether extreme accommodation is required on account of the minuteness of the object or on account of lack of contrast between adjacent portions of the work, it is a condition which the eye naturally cannot maintain for long periods without fatigue.

It may be expected then, that in any work involving very close inspection, the normal eye will become less fatigued if its accommodation is reduced by the use of a suitable glass. There is however, a definite relation between accommodation and convergence which is disturbed if simple plus or minus glasses are worn by individuals having no error of refraction. Fortunately this relation is somewhat elastic, so that, if weak glasses are worn, the disturbance is small and the use of prisms to restore the normal relation may be unnecessary.

Description of Linking.

The process of linking is necessary in order to complete the work of the circular knitting machine. The hose as it comes from this machine contains a gap across the toe portion, which must be closed by linking together two rows of stitches or loops. The machine used for linking consists of a dial, rotating at a speed usually of from 16 to 18 revolutions per hour, and provided with a number of radial needles about five-sixteenths of an inch in length, on which the loops of the hose have to be placed.

In the experiment to be described in this report the operatives used machines having 20 or 22 needles to the inch, the machines being of the American pattern and having a diameter over the needle-points of 14½ inches.

Pl

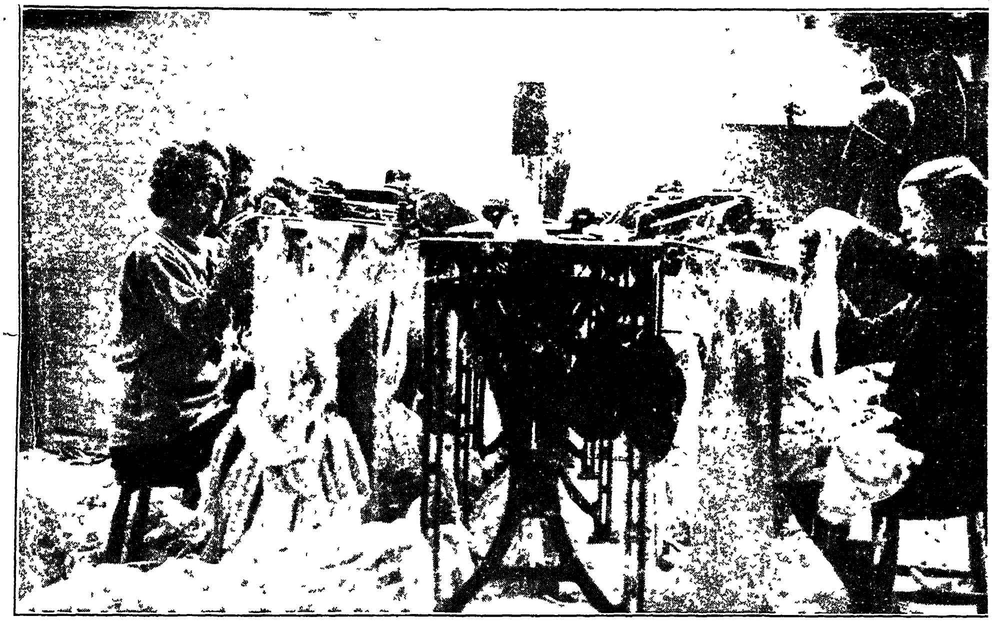
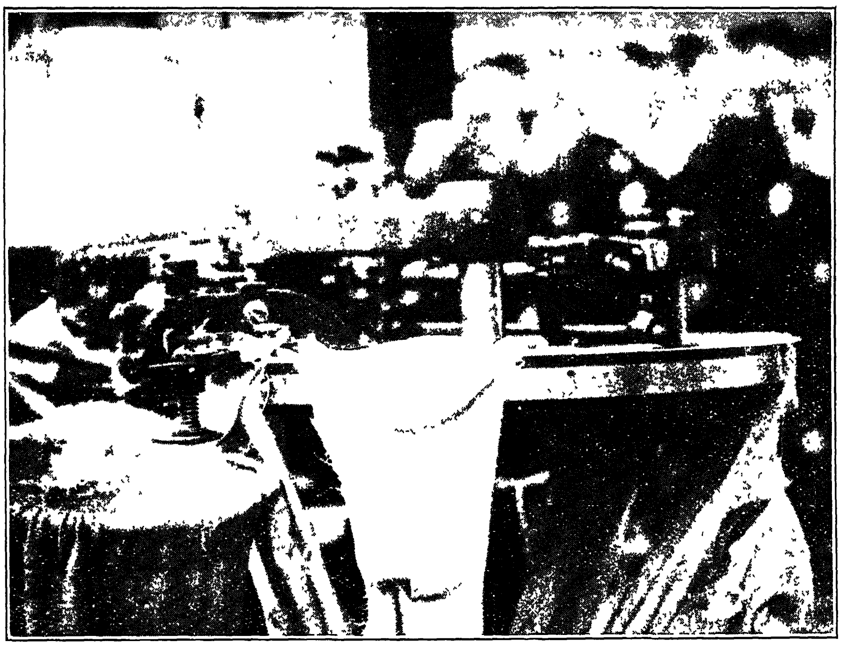
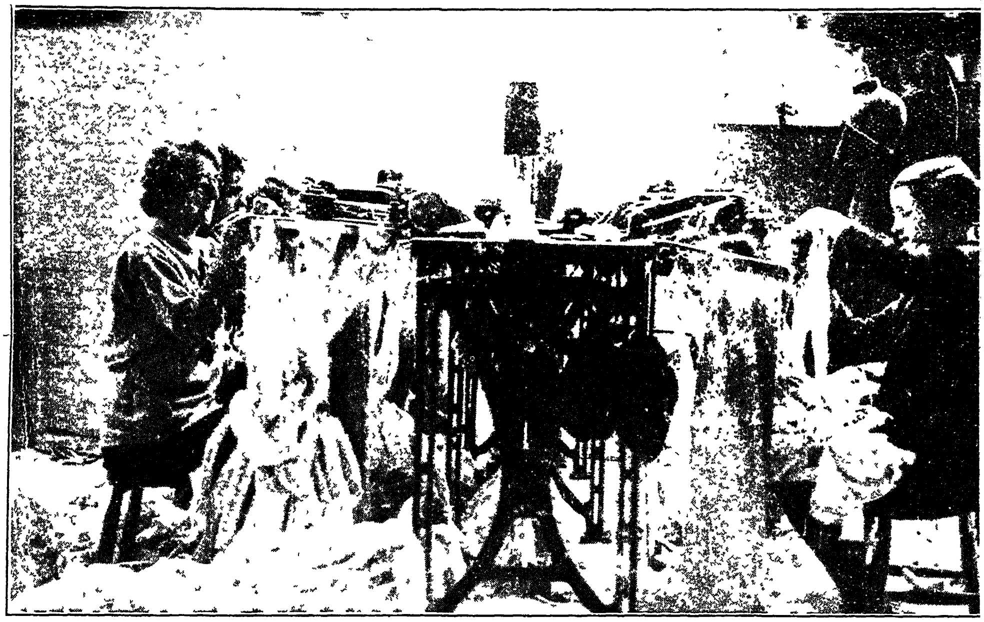
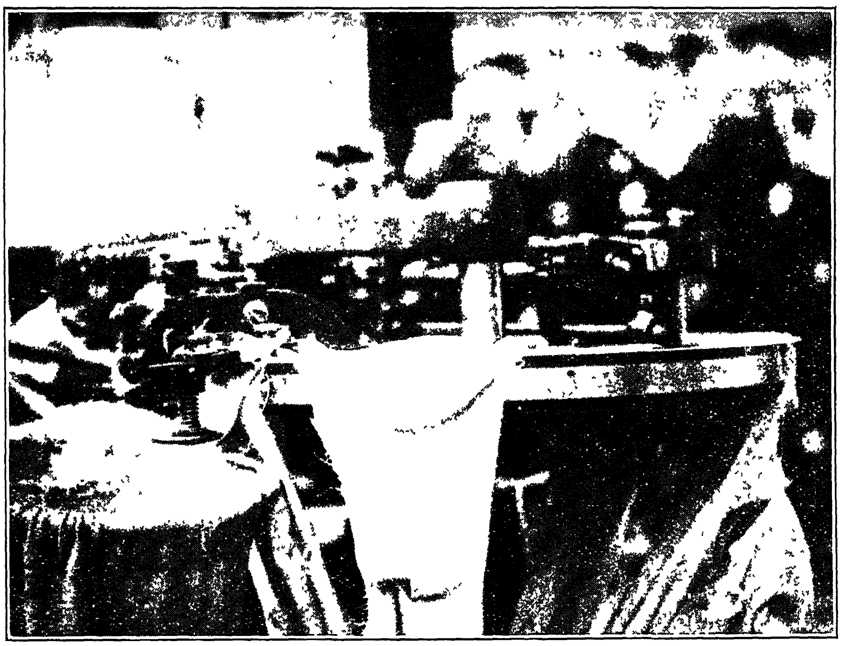


PLATE II







The operative sits on a low stool opposite the machine, her eyes being usually from five to eight inches from the needle-points, which she regards at an angle of approximately twenty degrees above the horizontal. The nature of the machine, and the distance at which the operative usually works, will be appreciated from the accompanying photographs, Plates I, II and III.

The fineness of the work itself is shown in Plate IV. which is a slightly enlarged photograph (about 1¼ to 1) of a piece of the actual hose linked by the experimental subjects.

The operative takes the hose by the loose end where it has been cut off by the knitter, and works the wales or loops on to the needles, taking care that all the loops put on are in the same course or row. A small amount of material is left above the needles for the operative to grip, but if the hose has been cut too short by the knitter, the amount of material left for gripping may be so small as seriously to increase the difficulty of the linking operation.

A 220-needle hose, which may be linked on a machine having 22 needles to the inch, has, of course, 220 wales or loops, so that, in order to close the cut portion at the toe, two rows of 110 loops have to be worked on to the needles While the hose is being placed on the needles the dial is slowly revolving in a clock-wise direction, thus carrying the hose round to a knife which cuts off the waste material. As the rotation of the dial continues, the parts of the loops or stitches above the needles are cleaned by means of a revolving brush, and the stitches are then brought in contact with a looper and needle which joins them and forms a seam. The linked hose is then removed from the dial as it comes round to the point at which the operative works.

The operative carries out the actual operation of linking during 75 to 80 per cent. of the factory working hours. The remainder of the time is spent in cutting hose apart after linking, booking work, collecting new work and delivering finished work.

The rotation of the dial can be started and stopped by means of either a hand lever or a pedal, and the stitches can be placed on the needles when the dial is stationary, though this is only done if the operative finds it impossible to keep pace with the machine, as may happen if she has insufficient material to grip.

If the hose is closely linked on the dial the speed of the machine would make it possible to link over six dozen pairs in one hour. The highest average of the quickest experimental operative was four and a half dozen pairs per hour. Hence at no time during the experimental period was the rate of working of the operatives retarded by the speed of the machines.

The Use of Spectacles.

This description of the process will make it evident that a high degree of accommodation and convergence of the eyes has to be maintained by linkers for long periods and, moreover, the eyes are fixed upon a very restricted area, so that staring is a characteristic condition imposed by the work These conditions tend to produce strabismus, or squint, a defect which is by no means uncommon among linkers. According to Fraschetti and Calamita*, hosiery operatives also experience a contraction of the field of vision, especially in the evening, while their visual acuity may be diminished and their susceptibility to other ocular affections, such as accommodative asthenopia (a form of eye-strain), increased.

From a consideration of the foregoing remarks it is apparent that the problem of relieving eyestrain among linkers is not confined to the question as to what is adequate and suitable illumination for the work, though a high standard of illumination is obviously essential. It seems surprising however, in view of the nature of the process, that the use of glasses, even by operatives having normal vision, has not previously been suggested and encouraged in this country. For a somewhat similar operation, that of cloth mending, the use of some form of binocular magnifying apparatus was suggested in France nearly twenty years ago, but, so far as can be ascertained, the suggestion has not been put into practice.

A considerable number of linkers find it necessary to wear glasses after several years at the work, and inquiries made preliminary to this investigation suggest that many who have not yet resorted to them would be well advised to do so. Some linkers, though recognising that the work is straining their eyes, are reluctant to wear glasses until the necessity for them becomes urgent. This is shown by the statements of operatives questioned, one of whom remarked that she did not wear glasses until Thursday or Friday, in each week, by which time she found it impossible to continue the work without them.

The details to be observed in linking, though small, are not so minute that a large magnification is required and, therefore, no apparatus similar to the watchmaker's glass, which restricts the field of vision, appears to be necessary. For the purpose of an initial experiment, ordinary spectacles which would reduce the amount of accommodation from that necessary at six and a half inches, to that necessary at say nine or ten inches, i.e., comfortable reading distance, were considered to be suitable. Thus, for the emmetropic (normal) eye $+1\cdot5$ glasses are required, and this value is sufficiently low to ensure the probability that no undesirable effects will result from their use, in spite of the absence of prisms arranged to preserve the normal relation between accommodation and convergence.

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* Fraschetti and O. Calamita. "Prime Ricerche per l'Organizzazione Scientifica del Lavoro." Ufficio Municipale del Lavoro. Rome 1920.

In the case of the emmetropic eye, the amount of accommodation required when viewing an object at a distance of six and a half inches is six dioptres, with a corresponding convergence of six metre angles. If $+ 1 \cdot 5$ glasses are worn, an object viewed at the same distance will be seen clearly when the amount of accommodation is $4 \cdot 5$ dioptres, i.e., as if the eyes were nine inches away from the object.

The ophthalmological examination of the experimental subjects studied in this investigation, and the prescription of suitable glasses, was very kindly undertaken by Mr. W. B. Laws, M.B , F.R.C S., of Nottingham, to whom our thanks are due for his interest and advice. A note by Mr Laws on his examination is included in Appendix II.

Lighting Conditions

Before describing the method of investigation, the conditions of illumination in which the operatives worked will be considered. The experimental room formed part of a new single storey building provided with north and side lights giving excellent daylight illumination. The machines of the three operatives referred to in this report were situated near a large window as shown in the accompanying diagram, Fig. 1. Operatives A and B were seated at positions 1 and 2 respectively, and operator C (a learner) at position 3 The two former therefore received illumination from the left, and the third, illumination from the right, in addition to illumination from the top lights. Adjoining buildings were not sufficiently near to affect appreciably the light obtained from the side window, and the consensus of opinion among the six operatives working at the bench shown in Fig. 1, was that both natural and artificial lighting was excellent.

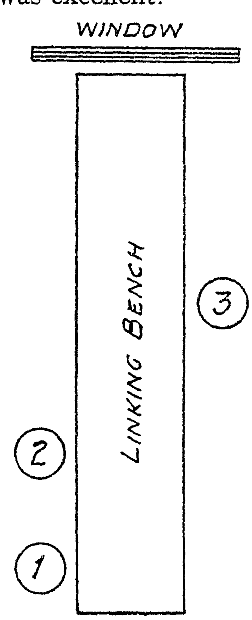

Fig. 1.—Plan of Linking Bench

A number of photometric observations were made to determine the daylight factor (sill ratio) at the work bench, and this was found to be 17 per cent. The outside readings were taken at the window ledge adjoining the linking bench, and the inside readings were taken with the standard surface of the lumeter placed on the points of the machine at an angle of 20 degrees from the horizontal plane. The lowest inside reading obtained was 16·2 ft. candles, and the highest, 34·3 ft. candles (the readings were taken in December), the average being 24·5 ft. candles.

Artificial illumination was provided by means of local lights mounted on universally jointed brackets so that they could be adjusted to suit each operative Twenty-watt lamps were used with hood type reflectors.

The operatives set their lamps above and slightly behind their heads in such a position as to throw a fairly uniform illumination on the working area of the dial. The distance between the pip of the lamp and the points of the dial was usually about 12 inches, but operative A generally arranged her lamp a little nearer to the working points than the other two operatives.

The illumination was measured at three points on the dial with the lamps set by the operatives in a typical position. All the readings, the averages of which are given in the accompanying table, were taken with the lumeter standard surface placed at an angle of twenty degrees from the horizontal, this being the usual angle at which the points are observed by the operatives.

Artificial Illumination of Linking Machines.

Distance from lamp (pip) to machine points (inches)	Position of standard surface (see diagram)	Illumination (foot-candles).
11·0	M	29·5
11·7	L	26·6
12·6	R	16·5

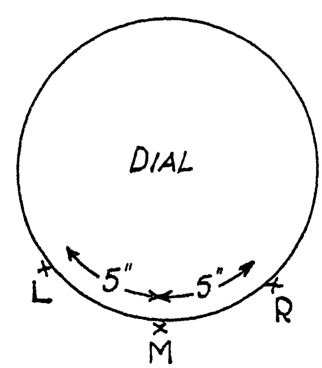

FIG. 2.—Plan of Dial.

The operative usually carries out the operation of linking between M and L, whether the dial is moving or stationary, and she therefore concentrates illumination on the area between these points. The principal objection to the system of illumination employed is glare, since, when the lamps are adjusted to the working position, the filaments are visible to operatives working on the opposite side of the bench. This will be appreciated on reference to Plate III. The distance from the operatives' eyes to the opposite lamp was approximately 4 ft. 6 in. in each case, and in addition three other lamps were visible. A number of measurements were made of the angle between a line from the eye of the operative to the opposite lamp and the horizontal plane, the average of these measurements being 14·6°.

The values of illumination observed during this investigation are not sufficiently low to suggest that illumination is a contributory cause of any eyestrain experienced by the operatives.

Method of Investigation.

The output of three operatives (two experienced and one learner) was recorded for a period of four weeks in order to determine the normal rate of working under existing conditions. The operatives were then examined and fitted with suitable glasses, and their output recorded during a second period of four weeks. During these two periods the three operatives produced the whole output for the department of one particular class of hose, but as the demand for this was not quite sufficient to keep the operatives occupied during the whole of the factory hours, they occasionally worked on other hose. Output records were only obtained for the former class so as to avoid the introduction of a variable factor. Three spells were worked, namely from 8 a.m. to 10 30 a.m., 10.45 a.m. to 12 52 p m. and 2 10 p.m. to 6.0 p m Owing to the method of working adopted, it was not practicable to obtain output records at more frequent intervals during the day. However, in order to obtain a record of hourly variations in the rate of working, a number of timings were made by means of a stop-watch, and from these the work curve for a typical composite day has been plotted

During the fifteen-minute morning break the operatives left the room and were able to obtain coffee, milk, biscuits, etc., if they wished to do so. The afternoon spell was continuous. The output records obtained show the number of dozens of hose (12 pairs, or 24 single hose) linked during each section of the day. In addition an analysis of lost time was kept which included separate records of time lost due to waiting for work, mechanical breakdown, illness, accidents, absence and miscellaneous causes. A record was also made of the time during which artificial light was used. For the purpose of comparing the data obtained, the net working time has been divided by the number of dozens of hose linked so as to give the time per dozen. In all the curves plotted the time scale reads downwards, so that a rise of the curve indicates an increase of output.

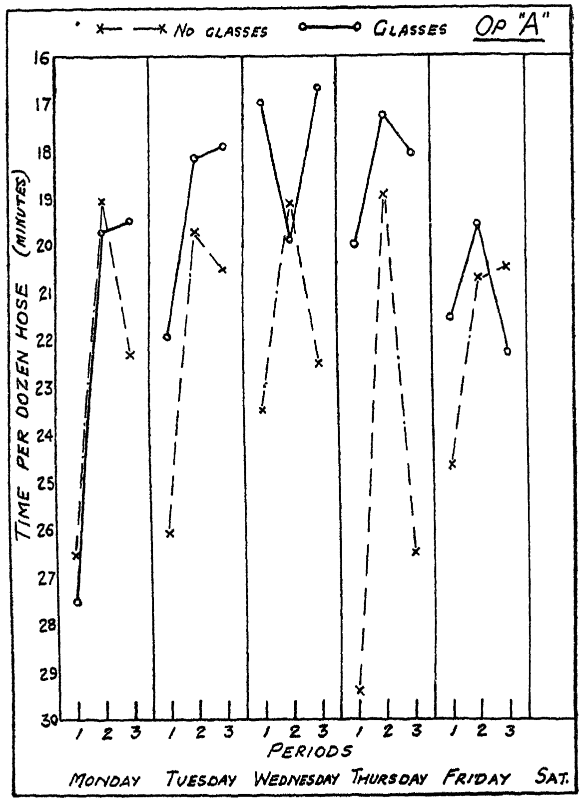

Fig 3.—Output of Operative A.

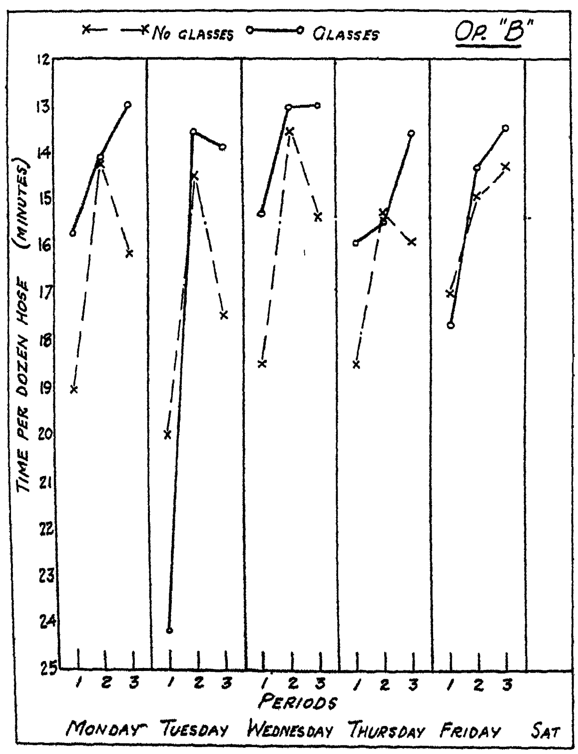

Fig. 4.—Output of Operative B.

Discussion of Data.

In Table I the times required to link one dozen hose during each period of the day, for subjects A and B, is given for each day of the typical week, both with and without the use of glasses. These figures are also plotted graphically in Figs. 3 and 4.

Table I.—*Time (in seconds) per dozen hose for linking (and associated operations) during each period of the day.*

Subject	Periods						Day.
	No glasses			Glasses.			
	1	2	3	1	2.	3.	
A.	1,594	1,146	1,337	1,653	1,184	1,167	Mon.
B	1,145	854	971	948	847	780	
A.	1,567	1,187	1,227	1,316	1,090	1,073	Tues
B.	1,201	872	1,046	1,450	818	831	
A.	1,408	1,149	1,352	1,017	1,193	1,001	Wed
B	1,110	815	920	918	781	780	
A	1,763	1,136	1,589	1,200	1,033	1,088	Thurs.
B.	1,109	913	954	955	926	819	
A.	1,480	1,247	1,227	1,296	1,179	1,336	Fri
B.	1,020	895	854	1,060	857	806	
A.	1,476	—	—	1,287	—	—	Sat.
B.	1,069	—	—	915	—	—	

These data show that the use of the glasses has been followed by two important results. In the first place, the general rate of output has been increased, for the figures indicate that, with few exceptions, a saving of time was effected during each period of the day when glasses were worn. Secondly, the shape of the output curve has been improved, since the usual fall of the curve on the afternoon spell is frequently reversed during the period when the glasses were in use. There is, therefore, evidence of progressive fatigue during the pre-glasses period and of its elimination with the advent of the glasses.

The periodic variations during the day of subject C, who was inexperienced and was not a full time linker, do not show this absence of fatigue in the afternoon. Her output, as might be expected, was much more variable than that of the other subjects, but there was a marked increase in her rate of working at each period of the day when glasses were worn.

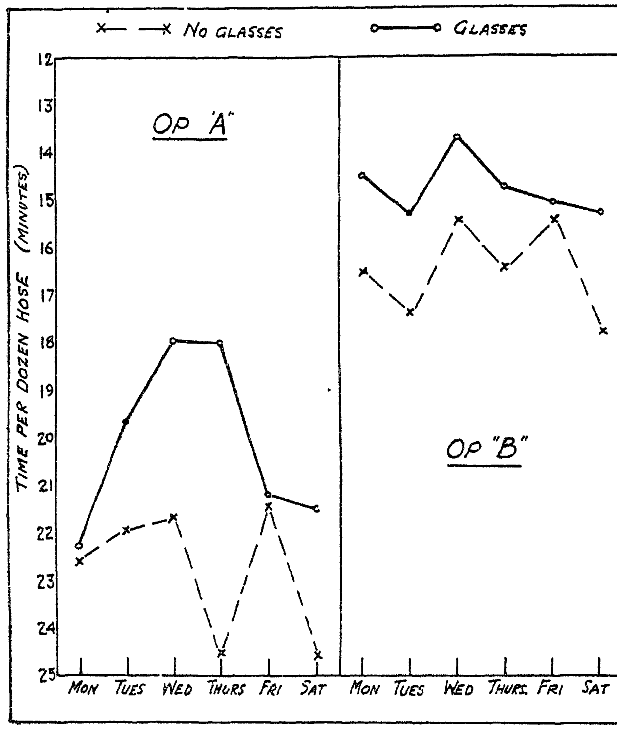

Fig 5.—Average daily output (Operatives A and B).

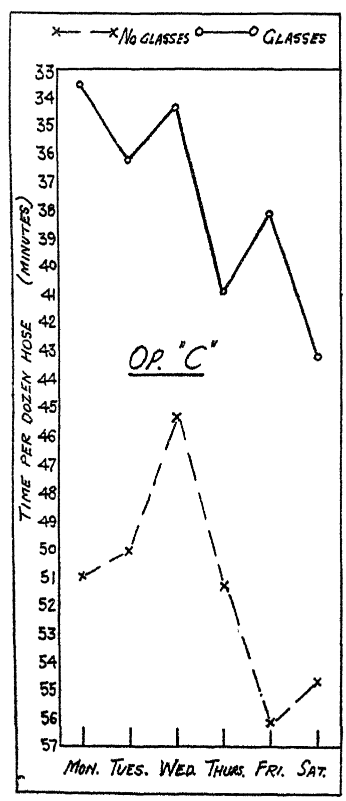

Fig. 6.—Average daily output (Operative C).

The figures given in Table II, and plotted in Figs. 5 and 6, show that, during the typical week, there is a consistent increase in the rate of working when glasses are worn. In the case of subjects B and C the curves are roughly parallel throughout the week.

TABLE II.—*Time (in seconds) per dozen hose for linking (and associated operations) during each day of the week.*

Subject	Day	No glasses	Glasses
A	Mon	1,359	1,337
	Tues	1,317	1,182
	Wed	1,303	1,079
	Thurs	1,471	1,080
	Fri	1,285	1,271
	Sat.	1,476	1,287
B	Mon.	991	870
	Tues	1,040	917
	Wed	926	820
	Thurs	981	888
	Fri	923	903
	Sat.	1,069	915
C	Mon	3,054	2,018
	Tues	3,006	2,174
	Wed	2,720	2,065
	Thurs	3,075	2,451
	Fri	3,368	2,287
	Sat.	3,280	2,595

The weekly variation in the rate of working, with and without glasses, is shown by the data given in Table III and plotted in Figs. 7 and 8. Here again the curves are practically parallel, the level being raised considerably during the period when glasses were worn. The improvement is, however, more marked in the case of the poorer worker and most marked in the case of the learner, thus suggesting that, to some extent, A's inferiority was due to inferior sight, and C's progress was retarded from the same cause.

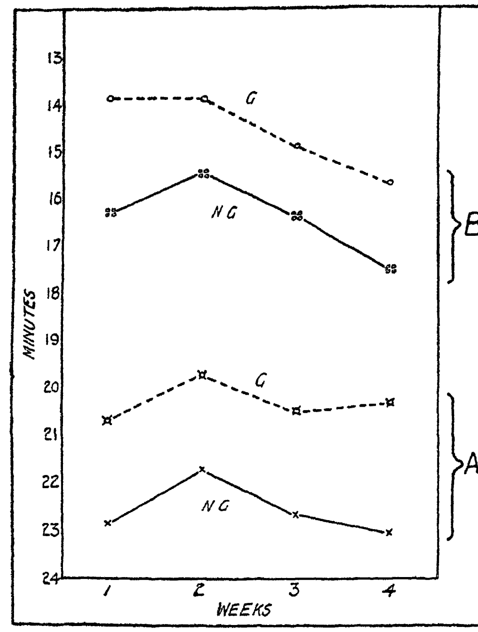

FIG. 7.—Average weekly output (Operatives A and B).

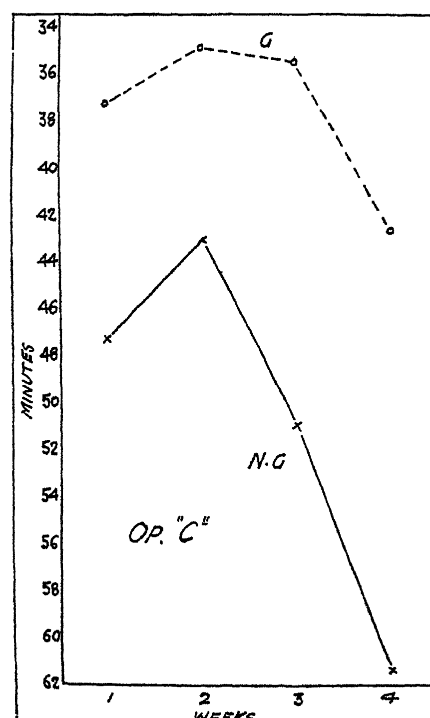

FIG. 8.—Average weekly output (Operative C).

TABLE III.—*Time (in seconds) per dozen hose for linking (and associated operations) during each week of the experimental periods.*

Subject.	Week	No glasses	Glasses
A	1	1,370	1,244
	2	1,307	1,187
	3	1,360	1,227
	4	1,386	1,217
B	1	975	831
	2	926	832
	3.	981	893
	4	1,052	943
C	1.	2,838	2,240
	2.	2,588	2,094
	3.	3,060	2,138
	4	3,685	2,569

In Table IV the average time required to link a dozen hose during the control month, and during the subsequent month when glasses were used, is given for each subject, together with the percentage decrease in time during the latter month. The decrease in the case of subjects A and B, i.e., over 10 per cent. is too high to be accounted for except as a direct result of the use of the glasses. The saving effected in the case of Subject C is nearly 27 per cent., and though a considerable proportion of this is doubtless due to other factors, such as increased skill acquired during the period of the experiment, it must be attributed largely to the beneficial effect of the glasses.

TABLE IV.—*Average time (in seconds) per dozen hose for linking (and associated operations) for each experimental period.*

Subject.	No. glasses	Glasses.	*Per cent. decrease in time due to glasses.*
A	1,356	1,218	*10·18*
B	986	885	*10·25*
C	3,044	2,234	*26·61*

Since ordinary records of output could only be obtained three times daily, a number of timings of net linking time (exclusive of subsidiary operations) were made, as explained in describing the method of investigation.

These times for subjects A and B are given in Table V, from which Fig. 9 has been plotted. These figures show unmistakably the beneficial effect of the glasses in increasing the rate of working and improving the shape of the work curve.

The actual saving of time was the same in the case of both operatives, i.e. about one minute per dozen hose, but since B was a faster worker than A, this represents a time saving of 7·36 per cent. in her case, as compared with 6·29 per cent. in the case of A. These percentages are lower than those shown in Table IV, so that it is evident that the glasses enabled the subsidiary operations to be performed with a proportionately greater saving of time than the actual linking, while, owing to the reduction of ocular fatigue, probably fewer voluntary pauses were made during the day than was the case when no glasses were worn.

TABLE V.—*Net linking time (in seconds) per dozen hose during a typical composite day.*

Time.	Subject A		Subject B.	
	No glasses	Glasses	No glasses.	Glasses
8— 9	1,028	964	769	705
9—10	987	939	771	701
10—11	961	907	759	692
11—12	1,041	914	709	671
12— 1	966	922	705	691
2— 3	949	886	718	660
3— 4	1,017	949	692	658
4— 5	931	908	742	653
5— 6	995	924	739	685

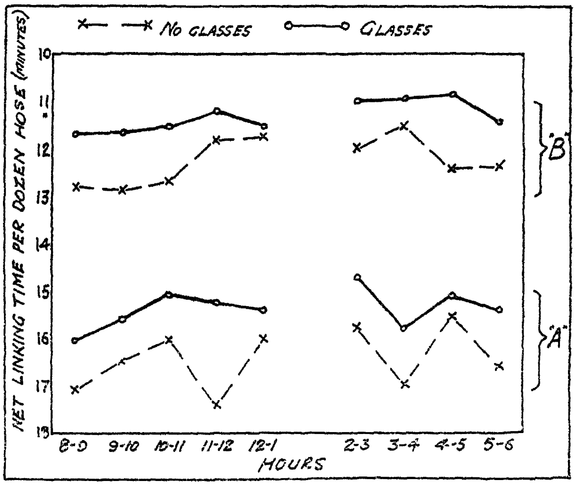

FIG 9.—Average hourly output during a composite day. (Operatives A and B.)

CONCLUSION.

The data presented in this report show that for each subject a considerable increase in the rate of working accompanied by a reduction of fatigue, has been effected as a result of the use of suitable glasses. These glasses relieved only the strain due to extreme accommodation, and it is possible that greater benefit might be obtained by the use of glasses which would also reduce the degree of convergence required. No discomfort was experienced by the operatives wearing the glasses and no subjective evidence could be obtained of any disturbance of normal vision when the glasses were discarded at the end of the working day. All the experimental subjects continued to wear the glasses after the completion of this investigation, and their comments upon them are given in the appendix to this report.*

There appears to be no reason why beneficial results should not follow the use of suitable glasses by other persons having normal vision who are engaged in performing operations in different industries which make demands upon their visual apparatus similar to those characteristic of linking. It is necessary, however, to emphasize the need for proper examination and prescription, as the value of the glasses will depend entirely on their suitability for any particular individual, and on their adjustment, e.g. angling, for the usual conditions of work.

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* Subsequent inquiry, made as this Report goes to Press, shows that all three operatives are still wearing these glasses during working hours

APPENDIX I.

Comments of Experimental Subjects.

Before using special glasses.

Subject A Experience 18 years Questioned about the operation of linking she said, " I find no difficulty in doing this work I get a head-ache now and then, but I don't think it is due to my work. My sight is good at a distance "

Subject B Experience 11 years This operative said, " I sometimes feel tired when doing this work " She then went on to say, " I feel most tired when bad work comes from the men " She spoke of tight and loose knitting and seemed to imply that her " tired feeling " was due to irritation and annoyance because of bad knitting She commenced work as a linker when she left school at the age of fourteen. She went to the doctor some time ago because she was suffering from head-ache. The doctor recommended the use of glasses, but she did not take his advice The head-aches have recurred occasionally since then

Subject C. Experience 1 year on half time. She said, " I can do this work comfortably and do not have any eye-strain. I have occasional head-aches "

When using special glasses

The special glasses were worn by the three operatives from 4th January, 1926, (the first day of the experiment) onwards, with the exception of the period 8 a m. to 11 35 a m., 6th January, when they were taken to have celluloid bridges fitted. On the 12th January, rimless spectacles replaced the original ones with nickel frames, and were worn for the whole of the working time during the period of the experiment.

During the first two or three days of use there was a tendency for all three operatives to work at a slightly greater distance from the machine than formerly. By the end of the first week all had returned to their normal distance.

The comments quoted here were collected at various times during the period of four weeks the experiment was in progress.

Subject A. During the first day the glasses were used all three subjects said the glasses were quite comfortable though they would have preferred rimless spectacles. The original lenses were fitted in nickel frames. On the second day of the experiment operative No 1, said, " I could see better at work last night, and I could see the stitches more clearly. My eyes didn't ache in electric light last night." Other comments expressed were, " I don't mind whether I use them or not " (Meaning she had become used to them) " They're all right at night." " My eyes don't ache at night as they used to do." " I feel much better when I get home at night." " I think I shall use them after the experiment, and if I don't wear them all day I shall certainly use them when the lights are on or when my eyes feel tired " " I left my glasses off for about ten minutes last night and I couldn't see my work anything like so well." " I think the glasses are very helpful. I would recommend other girls doing this work to use them. I don't think they make you work any faster, but they make you feel more comfortable "

Subject B. The comments of this operative were similar to those of A. They worked side by side. Other comments made by B were " They make the stitches look bigger " " We're very pleased with them and are now quite used to them." (The glasses had been in use ten days.) " We don't get tired eyes at night as we used to do "

Subject C (Learner). " I hadn't noticed much difference until yesterday : they're all right and I feel comfortable in them " (The glasses had been in use three days) " I like to do sewing at night Before I used the glasses my eyes used to ache Now I can sew at night without my eyes aching at all I think I shall keep using the glasses after the experiment "

Each operative was asked at the end of the experiment whether she would write a few notes stating her opinion of the value of the glasses for the operation of linking The following are the notes :—

Subject A " The glasses supplied to me for the use of my work as a linker here have been very useful Normally I have very good eyesight, but for the use of my work I find them a very great advantage They give ease to my eyes and are a great help "

Subject B " I found the glasses provided for me about a month ago a very great benefit to me in the very close work in which I am engaged as a linker in the hosiery trade I have very good eyesight but for use at my work they are a great help I can see the work much clearer and my eyes feel more rested at the end of the day."

Subject C " I have had the glasses you gave me about a month now and I get several benefits from them. They are very comfortable to wear and ease the eyes I can also see my work clearer, and my eyes never ache now at night I am able to get more work off with them "

APPENDIX II.

Note by Mr. W. B. Laws, M.B., F R.C.S.

Mr H C. Weston, who is investigating the use of magnifying glasses in linking, asked me to examine the eyes of a certain number of hosiery workers with a view to giving them suitable glasses

The following was the method adopted The refraction having been approximately determined—by retinoscopy checked by subjective testing—and any required correction placed in the trial-frame, the distance at which the operative habitually worked was ascertained and she was allowed to choose the additional spherical glass which gave her most distinct vision at that distance It seemed better to adopt this plan rather than that of giving a theoretically determined amount, as it allowed for differing individual powers of accommodation—the amount ranged from $+0\cdot75^{D}$ to $+1\cdot75^{D}$, but was in most cases near $+1\cdot5^{D}$. The glasses so determined were ordered in a frame centred for the working distance—usually about 9 inches—and considerably angled to allow for the downward direction of the visual axis which the work entails.

No cases of marked astigmatism occurred among those examined, and minor degrees were neglected (except in one case in which correcting glasses had already been worn)

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REPORT No. 41.

Rest Pauses in Heavy and Moderately Heavy Industrial Work

By H. M. VERNON, M.D., and T. BEDFORD, B.Sc.,
assisted by C. G. WARNER.

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PREFACE.

During the past few years much attention has been paid by the Industrial Fatigue Research Board to the effects of breaking up the usual spells of work by means of short rest pauses of definite duration and interpolated at definite intervals within the spell The results obtained strongly suggest that in many industrial processes the judicious introduction of short pauses is not only much appreciated by the workers, but may also be followed by an increase in output of the order of 5 to 10 per cent., in spite of the diminution of working time

These investigations have dealt almost wholly with light repetitive work, in which, boredom and monotony being the operative factors rather than fatigue, the beneficial effects of rest pauses have depended on change from the main operation rather than on the complete cessation of work In work involving hard muscular effort, however, the part played by rest pauses is different They are rests in the literal sense and serve as recovery periods from the effects of physiological fatigue

Recent researches, also, into exercise of an athletic kind, calling for maximal effort, have led to many gains in knowledge of the relations between efficiency and the rate of work, and of the rates of recovery after spells of work Here again the conditions are different from those of heavy industrial work Violent exercise is characterised by the accumulation of lactic acid in the muscles and blood, leading if continued long enough to exhaustion, and the conclusions reached are not necessarily applicable to industrial work carried on continuously for several hours in which the worker automatically tends to adjust himself to such a speed of working that the lactic acid does not accumulate but is removed by oxidation as fast as it is produced

Little knowledge indeed is at present available as to the effects of rest pauses *per se* in muscular work as done industrially, previous investigations of the subject having usually dealt as well with other important changes in working conditions The Board accordingly resolved, on the recommendation of the Committee on the Physiology of Muscular Work, to initiate some investigation of the subject, and as a preliminary step to publish the present report, which consists essentially of a series of analyses, based on actual observation, of a number of men engaged in different processes. It deals therefore only with existing conditions and not with any experimental alterations in the working periods.

The chief conclusions reached are, first, that in uniform work the alternation of activity and rest naturally adopted by the worker is approximately regular ; secondly, that, as would be expected, a direct relation exists between the total length of rests spontaneously taken and the arduousness of the particular work , and lastly, that, from the point of view of recuperation, rests brought about by circumstances outside the control of the subject (such as waiting for material) are ineffective in comparison with rests taken voluntarily

January, 1927.

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REST PAUSES IN HEAVY AND MODERATELY HEAVY INDUSTRIAL WORK

By H. M VERNON, M D , and T BEDFORD, B Sc., Investigators to the Board, assisted by C. G. WARNER.

CONTENTS.

INTRODUCTION.

In a previous report (No. 25) we showed that the introduction of brief rest pauses, lasting five to ten minutes, in the middle of the work spells of operatives engaged on light repetition work, caused a small improvement of output in most of the occupations investigated. This result has been confirmed by Wyatt (1925) and by other investigators, and probably it holds good for most types of light repetition work. It does not necessarily apply, however, to heavy work, for in such work it is physically impossible for the operatives to continue for long without a break of some sort. They are bound to take rests at frequent intervals, whilst in light labour they may continue steadily at their tasks throughout the work spells with scarcely a break. It may nevertheless be advantageous to arrange the rests taken by heavy workers on some regular scheme, and in order to obtain light on the subject, we have made observations on the rest pauses taken by such workers whenever opportunity offered. These observations, taken in conjunction with those recently made on coal miners, help us to draw conclusions about the desirability and the practicability of introducing schemes of rest pauses for heavy workers.

Falling between typical heavy workers and those engaged on light repetition work come numerous groups of men—and occasionally of women—who are employed on moderately heavy work. Such individuals could probably continue at their work without a break if compelled to do so, but this would cause undue fatigue and diminished output, so inevitably they take occasional rests. It is of interest to determine the extent of these rests, as compared with those taken by typical heavy workers. Though there is no hard and fast line between heavy workers and moderately heavy workers we find that in actual practice it is usually fairly easy to distinguish between them. One of us (Vernon, 1920) drew up a scheme in which all workers were divided up into five classes, distinguished by the numerals 1 to 5, according as their work was very light, light, moderate, heavy, or very heavy, and each of these classes was divided into three groups. The moderate workers, for instance, were divided into the three groups labelled 3—, 3 and 3+, and the heavy workers into the three groups of 4—, 4 and 4+. It was supposed that between the 3+ and the 4— groups of workers there was roughly the same difference in the severity of the work performed as between the 3 and the 3+ groups, or between the 4— and the 4 groups. By careful observation of the work done, and of the atmospheric and other conditions under which it is performed, it is usually possible to place a worker with fair assurance, and all the workers referred to below are classified on this scheme. Admittedly it is only provisional; but it does at least indicate the mature opinion of investigators who have spent much time in making first hand observations on the various groups of industrial workers.

Spontaneous Rest Pauses Observed in Moderately Heavy Work.

The moderately heavy work investigated consisted mostly of various kinds of outdoor labour. An investigator could usually watch two workers at a time, and he observed them for a one-hour or two-hour period. All the rests taken were noted to the nearest ¼-minute. Most of the observations were made in the spring, under pleasant weather conditions.

Road-making, etc.—Observations were made on 34 men engaged in road-making, and in shifting earth and sand. The simplest and most regular task was that of picking up the road surface, for the men employed had no break in the uniformity of their task except a very occasional brief walk. Typical observations on two men for a two-hour period are recorded in Fig. 1 (a), and it will be seen that both of them took a brief rest (R) at intervals of about six minutes with considerable regularity. The total rests taken by these men and by the eight other men investigated, had an average duration of 11·9 minutes per hour, or at the rate of about 1·2 minutes per rest. The main operation of picking is labelled M, whilst walking is labelled W.

A number of men were occupied in shovelling loose earth into wagons, and they too had no break in the uniformity of their work except for an occasional brief walk. It will be seen from

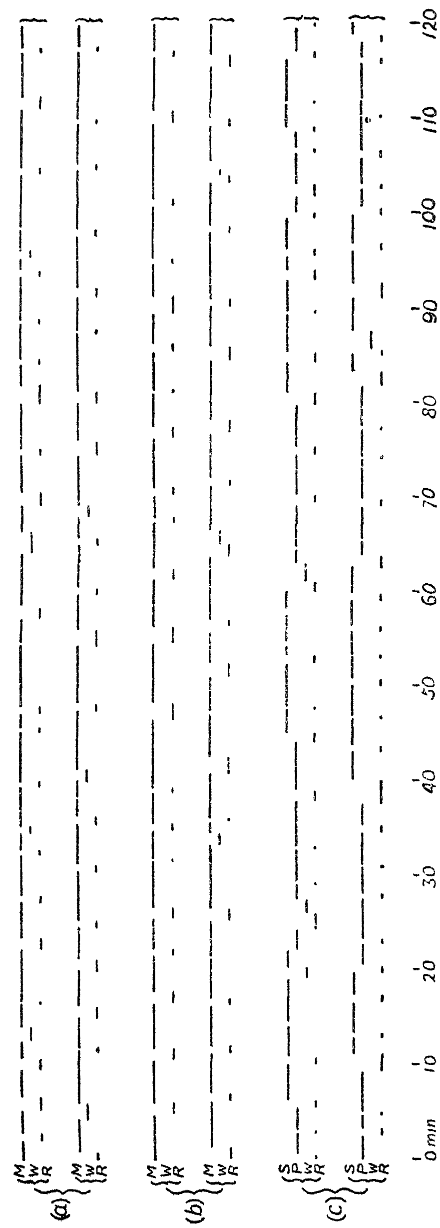


FIG 1. Rest pauses taken by men engaged in (a) picking road, (b) shovelling earth, and (c) shovelling and picking sand

Fig. 1 (b) that they took rests from work with the same regularity and frequency as the road pickers. The total rests taken (by eight men) averaged 11·5 minutes per hour, or practically the

same as before. Though these rests are probably unnecessarily long, and perhaps too frequent, there can be little doubt that in so far as *regularity* is concerned, the men need no guidance. They spontaneously, and doubtless quite unconsciously, adopt an extremely regular and rhythmical system of rests. We shall see that this regularity holds true only so long as the work done is of a regular character. When it consists of various jobs, which have to be performed at irregular times, the rest pause rhythm is upset, and the more irregular the work the more irregular the rests. In Fig. 1 (c) are reproduced the observations made on two men who were alternately shovelling sand (S) and picking it (P), with a very occasional walk interposed. The rests were about 50 per cent more numerous than in the two preceding occupations, and they were somewhat less regular in duration. However, their total duration was about the same, as it averaged 12·4 minutes per hour (for five men). It is rather surprising to find that the groups of men employed in different occupations should have spontaneously adopted such remarkably similar habits in regard to the amount of rest taken, and we shall see that other groups of men, employed on other and more widely divergent tasks, resembled them closely, as a rule. However, in one group of five men, who were shovelling earth into barrows, and wheeling them, the average rests amounted only to 8·0 minutes per hour. These rests were taken with about the same regularity as those shown in Fig. 1 (c).

When we pass to distinctly less regular jobs than those referred to, we find the rest pause rhythm more definitely upset. In Fig. 2 (a) are recorded observations on men who were shovelling sand into tubs in a sand pit. Occasionally they had to walk along

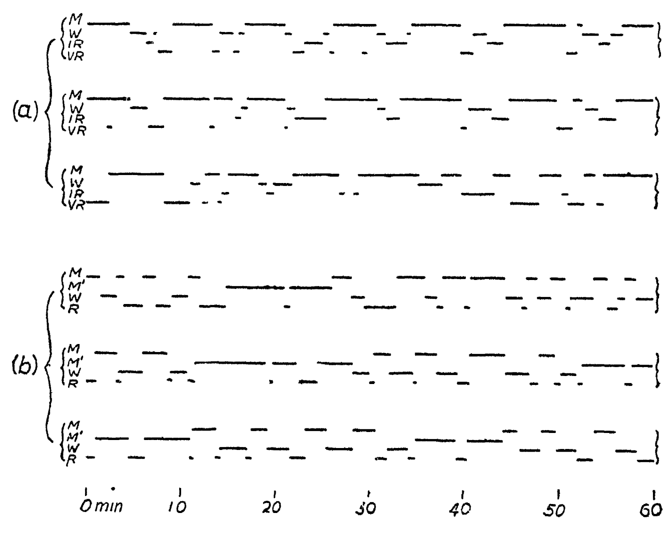


FIG. 2. Rest pauses taken by men engaged in (*a*) shovelling sand, and (b) bricklayers' labouring.

pushing the tubs (W), and frequently there was a shortage of tubs for them to fill. The involuntary rest pauses (IR) so induced caused the voluntary rests (VR) to be much less numerous and

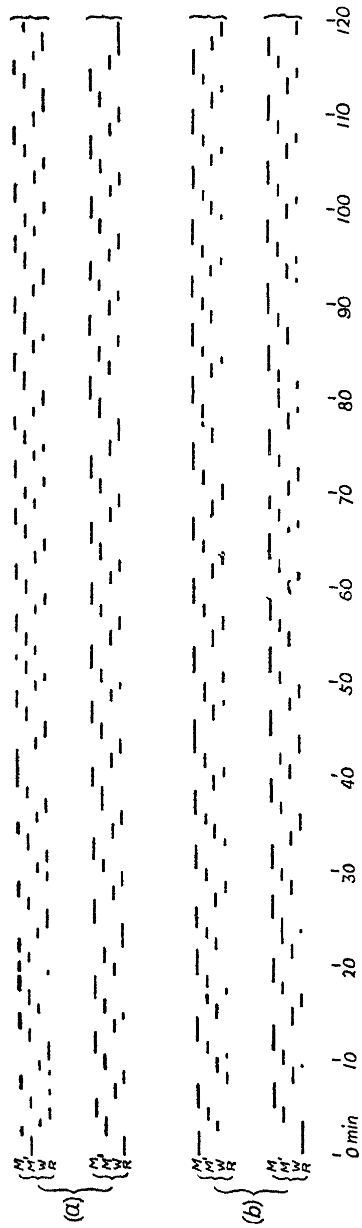


Fig. 3. Rest pauses taken by men engaged in (a) unloading timber, and (b) unloading sacks of grain.

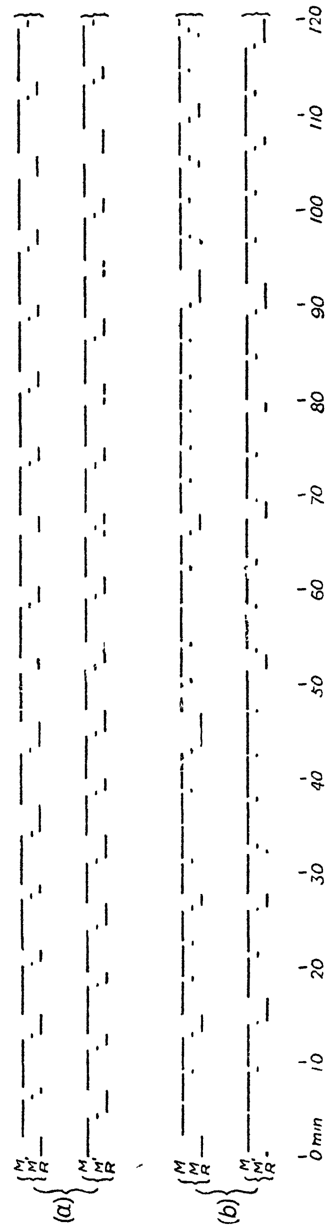


Fig. 4. Rest pauses taken by men engaged in (a) ploughing, and (b) harrowing.

regular, but their total duration (9·9 minutes per hour for six men) was not very much less than before, in spite of the 9·1 minutes per hour of involuntary rests. In Fig. 2 (b) are shown some results

obtained with bricklayers' labourers. Their main operation (M) consisted in loading or unloading materials, such as bricks and mortar, which had to be carried in a hod ; but they spent almost an equal amount of time (W) in carrying these materials, and a somewhat shorter time in mixing mortar and other subsidiary jobs (M'). Their rests averaged about the same as those of the road makers, viz., 11·1 minutes per hour, but it will be seen from the Figure that they were by no means so regular.

Dock work.—Another class of labouring work is illustrated in Fig 3. This relates to men at the docks who were unloading lengths of timber and sacks of grain from barges. They spent a minute or two in getting the load on to the shoulder (M'), and then walked up an inclined board to the shore and deposited the timber on a stack, or bestowed the sack in a warehouse (M). Then they walked back to the barge in order to fetch another load (W). It will be seen from Fig 3 (a) that the timber carriers were fairly regular in the frequency and duration of their rests, whilst for some unascertained reason the sack carriers were less regular. However, their total rests were practically the same, viz., 11·9 and 10·5 minutes for five and six men respectively, and corresponded with the rests observed in the road-makers.

Agricultural work.—A third class of outdoor labour is illustrated in Fig. 4. The first pair of records represent the work of ploughmen, where M is the main operation of ploughing a furrow, and M' the subsidiary one of turning the horses for the next furrow. At each turn a rather lengthy rest was taken, and observations on nine men showed that on an average the rests totalled 14·6 minutes per hour. This is about three minutes more than that taken by the other outdoor labourers, but men engaged on the lighter work of harrowing and rolling took considerably shorter rests. In both of these occupations the rests averaged 8·1 minutes per hour, and it will be seen from the results recorded in Fig. 4 (b), which relate to harrowing, that they were not very regular, as the men had no definite system Sometimes they did not take a rest until they had made four or five turns (M'), and at other times they took one after one or two turns. The soil over which they had to walk was much less heavy than that of the furrows through which the ploughmen plodded, so naturally the need for rests was smaller

Rest Pauses Observed in Piece-Rate Workers.

All the workers referred to so far were paid at a day rate, and on that account would not be inclined to exert themselves unduly. The rests taken averaged 10·7 minutes per hour, and we should expect that piece-rate workers, if put on to work requiring a similar expenditure of energy, would take considerably shorter rests than this, for we found (1924) that piece-rate operatives, when engaged on light repetition work, took less than a minute per hour. However, we could not decide the point definitely, as we

did not happen to come across any piece-rate workers who were closely comparable to the day-rate workers. The men employed on the heaviest kinds of work in boot and shoe factories have jobs which are similar in their demands on physical energy, but they are complicated by the fact that the men have frequently to wait for supplies of shoes, which are passed on to them after the completion of the previous stage. For instance, the 'pullers over' (who pull the upper over the last, and tack it lightly to the insole) were found, on an average, to take 2·7 minutes per hour of voluntary rests, but they had in addition 15·3 minutes of involuntary rests, due to lack of material. The 'consolidated lasters' (who secure the upper to the insole firmly, by means of tacks) took 2·4 minutes of voluntary rests, in addition to 5·1 minutes of involuntary rests, whilst the 'levellers' (who place the shoe on heavy iron lasts, and mould the sole into shape) took 3·5 minutes of voluntary rests, in addition to 11·1 minutes of involuntary rests. We shall see that in coal miners, the involuntary rests, because they are so irregular in frequency and duration, probably have only about a fifth the restorative value (from fatigue) of voluntary rests; but with boot and shoe men they are probably more valuable than this as they are briefer and occur with greater regularity. In any case, the consolidated lasters obtained only 7·5 minutes of rest per hour altogether, or distinctly less than the outdoor men, though their work is probably as heavy.

Observations were made on the boot and shoe men throughout the working day in order to determine if the rests taken were influenced by fatigue. The men were on an $8\frac{3}{4}$ hour day, and as they lost a great deal of time in starting and finishing at the beginning and end of the work spells, the first and last $\frac{1}{4}$-hours were considered separately, whilst the intervening times were cut up

TABLE I.—*Rest pauses taken by boot and shoe operatives.*

Time of Work Spell.	Rests (in minutes per hour) taken by				Mean corrected hourly output.
	4 levellers	4 pullers over.	6 consol lasters	Mean.	
8 0 to 8 15 ..	50·8	55·9	60·0	55 6	100
8 15 „ 9 15 ..	15·5	18·6	9·3	14·5	101
9 15 „ 10 0 ..	20·8	16·3	3·2	13·4	93
10 0 „ 10 45 ..	19·4	25·2	17·3	(20·6) } 12·9	99 } 99
10 45 „ 11.45 ..	11·4	21·8	9 4	14·2	98
11.45 „ 12 45 ..	11·2	15·1	3·0	9·8	102
12.45 „ 1.0 ..	27·2	42·7	29·2	33·0	86
2.0 „ 2 15 ..	34·3	44·0	52·4	43·6	108
2.15 „ 3.15 ..	13·4	14·4	6·1	11·3	104
3.15 „ 4.0 ..	14·7	13·6	5·4	11·2 } 12·2	99 } 103
4.0 „ 4.45 ..	14·7	18·4	9·1	14·1	106
4.45 „ 5.30 ..	12·7	19·5	5·9	12·7	104
5.30 „ 5 45 .	27·6	56·5	34·4	39·5	90
Mean rests per hour.	14·6	18·0	7·5	—	—

into 1-hour or $\frac{3}{4}$-hour intervals. From Table I it will be seen that though the individual groups of men showed considerable irregularities, yet the mean rests taken (reckoned per hour of work) were fairly steady. Ignoring the initial and final quarters of an hour, they came to 12·9 minutes per hour in the morning work spell, and to 12·2 minutes in the afternoon spell. Hence there was no sign of any fatigue effect in the afternoon. The rests taken in the 10.0 to 10.45 period are not included in the estimate as they were increased by about eight minutes owing to the men stopping for a brief meal. In the last column of the Table is recorded the average rate of production of the men during actual working time, and it will be seen that it was fairly steady, though rather greater in the afternoon than in the morning.

We consider that all the occupations described so far were either of a moderately heavy type, or were just on the border line of the heavy type. In Table II we have marked most of the occupations as 3+, whilst harrowing and rolling, which are somewhat lighter than the rest, are marked 3. Dock labour, which is probably heavier than the rest, is marked 4— ; i.e., it is considered to fall just within the heavy type. All the other occupations included in the Table are definitely heavy work. In pitch loading, gangs of 12 men work together on a mass of pitch, which has been run into a large reservoir and left till it has set solid. Four of the men, termed "getters," break it up by inserting wedges and crowbars, whilst six of the men, termed "fillers," load it into skips. The men investigated by us were paid at a differential piece rate, and got a higher and higher rate of pay the more pitch they loaded, so they had a very strong inducement to work their best. We watched three gangs of men for two days, the hours of work being from 8 or 8.30 till 12, and from 1 till 5, and we found that on an average each gang, as a whole, rested 14·3 minutes per hour. In addition, the getters were frequently resting when the fillers were working, and *vice-versa*, so that on an average the getters obtained 26·0 minutes of rest per hour, and the fillers, 21·7 minutes. Roughly speaking, therefore, they rested for a third to a half of their working time, and did only about four hours of actual work in the day ; but undoubtedly they put in a very hard day's work.

In the tinplate trade we have studied the work of the millmen on several occasions, and consider it to be even heavier than that of the pitch loaders, because of the high temperature at which it is performed. The processes involved have been fully described by one of us (Vernon, 1919) in a previous report, so it is only necessary to state here that steel plates or "bars," usually about 20 in. long by 9 in. wide, and weighing 20 to 40 lbs., are heated to a bright red heat and are flattened out by passing them between heavy iron rolls. This process is repeated five times in succession, and in three of the five stages the sheets of metal are folded over, or "doubled." About 30 bars are worked through at each heat, and it takes over an hour to accomplish the five stages of the rolling.

TABLE II.—*Rest pauses in various occupations.*

	Occupation	Character of work	Day rate or piece rate	Fatigue of work	Number of men investigated	Man-hours investigated	Rest pauses per hour in min. voluntary	Rest pauses per hour in min. involuntary.	Minutes of work. per hour.
Agriculture	Harrowing	Very regular	Day	3	3	4	8·1	0	51·9
	Rolling	,,	,,	3	2	4	8·1	0	51·9
	Horse ploughing	,,	,,	3+	9	13	14·6	0	45·4
Roadmaking, etc.	Picking up road surface ..	,,	,,	3+	10	14	11·9	0	48·1
	Picking and shovelling sand ..	,,	,,	3+	5	7	12·4	0	47·6
	Shovelling earth into wagons ..	,,	,,	3+	8	11	11·5	0	48·5
	Shovelling sand into tubs	Moderately regular.	,,	3+	6	7	9·9	9·1	41·0
	Shovelling earth and wheeling barrows	,,	,,	3+	5	7	8 0	0	52·0
Building ..	Bricklayer's labourers ..	Rather irregular.	,,	3+	5	7	11·1	0	48·9
Dock labour	Unloading timber ..	Moderately regular.	,,	4−	5	10	11·9	0	48·1
	Unloading sacks	,,	,,	4−	6	12	10·5	0	49·5
Boot and Shoe making ..	Pulling over	,,	Piece	3	4	35	2·7	15·3	42·0
	Consolidated lasting	,,	,,	3+	6	52	2·4	5·1	52·5
	Levelling	,,	,,	3+	4	35	3·5	11·1	45·4
Pitch loading	Getters	Moderately regular.	,,	4	18	(2 days)	—	—	34·0
	Fillers	,,	,,	4	12	,,	—	—	38·3
Coal mining ..	Workers at coal face ..	Very irregular.	,,	4 to 4+	138	220	5 to 9	1 to 13	53 to 38
Rolling tin plates ..	Behinders	Regular.	,,	4	6	7	7	14	39
	Second helpers	,,	,,	4	6	7	5	20	35
	First helpers	,,	,,	4+	6	7	7	20	33
	Rollermen	,,	,,	4+	6	7	7	7	46
	Furnacemen	,,	,,	4+	6	7	7	17	36
	Doublers	,,	,,	5−	6	7	5	23	32

All the men rest for a minute or two between each stage, and individually they get a long rest during one or more of the stages. Up to 1918 the men worked together in teams of four, and they kept their work going continuously through the eight-hour or six-hour shift. From 1919 onwards, two additional "helpers" have been introduced in each team, and only eight-hour shifts are worked.

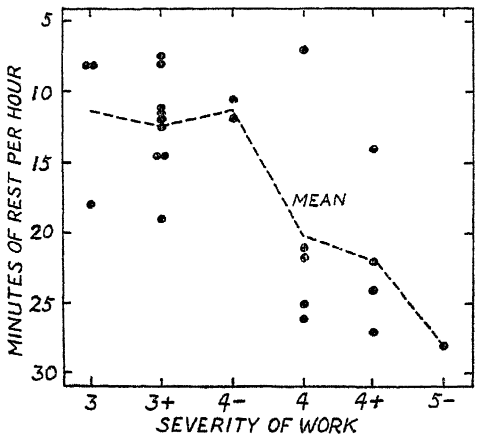
In 1918 it was found that, on an average, the millmen rested for 12·5 minutes per hour when on eight-hour shifts, and for 10·2 minutes when on six-hour shifts. The rests taken were very steady from hour to hour, and showed no fatigue effect. In order to obtain an exact measure of the rests taken under the modern scheme of work, we watched six teams of men through a heat, 36 bars weighing 31 lbs., each being worked through in each case. This took 69 minutes on an average, and the men rested, as a team, for eight minutes per heat, or seven minutes per hour. These rests were voluntary, whilst the times for which the men's services were not required in the scheme of work may be termed involuntary rests These rests, added on to the voluntary rests, brought the total resting time to a period which ranged from 14 minutes per hour in the 'rollerman' to 28 minutes per hour in the 'doubler' (*cf.* Table II). However, these times by no means represent the whole of the rests from active work. During the rolling, the red-hot sheets of metal are passed on from one man to another, and as the jobs required of them are not of equal duration, some of the men have to wait for a considerable interval between each sheet. The average periods of work and rest taken during the manipulation of each sheet in the five stages, were determined by making about 70 individual observations on each class of man. The mean results are recorded in Table III, and it will be seen that the rests varied between the extremes of 0·8 and 9·7 seconds per sheet. Allowing for these rest intervals, it was calculated that the various men were *actively* engaged only for 21 to 42 minutes per hour. The times of active work were . second helper, 21 minutes; first helper, 26 minutes, doubler and furnaceman, 27 minutes each, rollerman, 42 minutes.

TABLE III.—*Average duration in seconds of alternate work and rest periods during the rolling of each bar of tinplate.*

	Stage 1.		Stage 2		Stage 3.		Stage 4.		Stage 5	
	work	rest	work	rest	work	rest	work	rest	work	rest
Rollerman	13 4	0 8	nil	—	16 8	1 5	22 0	3 0	28·5	1 5
Doubler	nil	—	12 8	1 4	15·9	2 4	20 0	5 0	nil.	—
Furnaceman	nil	—	9·0	5 2	nil	—	22·4	2 6	20 3	9 7
First helper	6 6	7·6	13 5	0·7	17 8	0 5	17 9	7 1	nil	—
Second helper	9 5	4·7	7·5	6·7	nil.	—	part time.	—	part time	—
Duration of stage in minutes	8 5		8 5		11		15		18	

In spite of these tremendously long rests, we consider that the work of the tinplate millmen is harder than that of any of the other men investigated by us. From Table II it will be seen that we consider the work of two of the men to be 4, of three of them, 4+, whilst that of the doubler is probably the hardest of all, and is marked 5—. A special study of the severity of this man's work was made by one of us (Vernon, 1925), and it was found that the dry kata cooling power of the air where he was working varied from 0·5 to —3·7; i.e., it was frequently so hot owing to the intense radiation from the red-hot sheets of metal that the kata rapidly warmed up through its temperature range of 95° to 100°, instead of cooling. However, the wet kata cooling power was quite good, as it ranged from 18·5 to 23·3. Radiant heat causes a rapid evaporation of moisture from the wet bulb of the thermometer, with a consequent cooling effect, as was proved by control observations in the laboratory. As the doubler is always streaming with perspiration owing to the strenuousness of his work, he probably feels the heat less than one would expect, having regard to the dry kata cooling power of the air. Nevertheless, the physical strain of his work is very great, as was proved by taking pulse rates. Before starting on the first, and hardest, doubling of the metal sheets, the rate averaged 90 per minute, and at the end of this doubling it had quickened to 150 per minute, a rate which is usually observed only after very strenuous work such as boxing. After the end of the second and third stages of the doubling it averaged 125 and 119 per minute respectively.

In another report, (No. 39) we describe the results of our observations in coal mines, when 124 colliers (or hewers) and 14 trammers (or fillers) were kept under close observation for a period which averaged 96 minutes. All the rests from work were noted down, and the temperature, velocity and wet kata cooling power of the air at the various working places were ascertained; also the average time taken by the men to fill the 10 cwt. tubs of



.. Relationship between severity of work and duration of rest pauses.

coal. This information, coupled with the duration of the rest pauses, gave us a measure of the working capacity of the men in relation to atmospheric conditions. We consider that the work of the colliers and trammers is similar in its strenuousness to that of tinplate millmen, and we have marked it 4 to 4+. It is true that the rests taken were shorter than those observed in most other heavy workers, as they varied from 7 to 22 minutes per hour. Still, the data in Table II, if taken as a whole, undoubtedly support our contention that the more strenuous the work, the greater the duration of the rest pauses taken. In Fig. 5 the observed rests are plotted out in relation to the severity of the work, and it will be seen that they indicate a rapid increase of resting time for all work of grade 4 and upwards. The dotted line represents the mean of the rests observed in each grade.

Duration and Character of the Rest Pauses Observed with Colliers.

Arguing from the observations made on other industrial workers, we are in a better position to appraise the numerous results obtained by us with coal miners. As in other instances, all the rest pauses taken were noted down to the nearest ¼-minute, and we distinguished between such rests as were purely voluntary, those that were involuntary (due chiefly to lack of tubs), and those spent in discussing the work in hand. Such discussion was either with a deputy (i e. foreman), who visits each working place twice in each shift, or with a mate, and generally related to precautionary measures, such as the erection of roof supports. In Fig. 6 are reproduced a few samples of the rests observed. The first three samples represent the work of colliers under pleasant atmospheric conditions, the wet kata cooling power varying from 19 to 14. In (a) the collier was engaged at first in drilling the coal face (for shot firing), and later on, in holing and in shovelling coal. It will be seen that he took a number of brief voluntary rests (VR) from work at irregular intervals, and one or two rests (TR) in order to talk about the work, but at one period he worked continuously for 32 minutes. In (b) the collier was hewing and shovelling coal, but did no holing. It will be seen that he took a number of brief voluntary rests at irregular periods, and in addition had several involuntary rests (IR), two of which lasted over four minutes. In (c) the collier was mostly engaged in packing dirt, and he took voluntary rests at less frequent intervals. The work recorded in (d), (e) and (f) was performed under adverse atmospheric conditions, the wet kata cooling power being 6 to 9. It will be seen that the voluntary rests were, on the whole, of greater duration than before, whilst in two instances there was a long involuntary rest in the middle of each period of observation. It will be noted that for about 15 minutes after these involuntary rests the colliers took no voluntary rests, so they appear to have benefited by them to some extent.

In each of the sample records shown, as indeed in every observation made, the voluntary rest pauses were taken at most irregular intervals and were usually irregular in duration. This happened

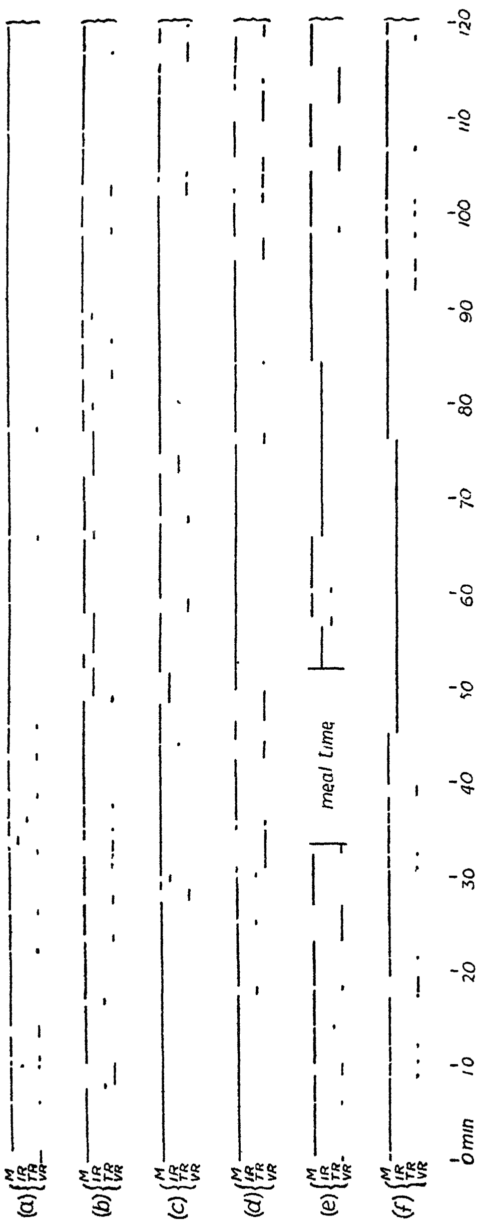


FIG. 6. Rest pauses taken by colliers.

almost inevitably because of the extreme irregularity in the nature of the work performed by the colliers. It would have been quite impossible to arrange any orderly scheme of rest pauses for

TABLE IV.—*Number and duration of rests taken by coal miners.*

Wet kata cooling power.	No. of observations.	Voluntary rests						Involuntary rests.						Talking.				
		Rests per hour.					Mean duration.	Rests per hour.					Mean duration.	Rests per hour.				Mean duration
		Total No.	¼ min.	½– min.	1– min	2 min. or more.		Total No.	Under 1 min	1– min	5– min	20 min or more		Total No	Under 1 min.	1– min	2 min or more	
12 and over ..	43	7·5	3·7	2·2	1·1	·5	·7	·6	2	·3	·1	·01	1 4	1·2	1·0	·1	·1	·6
11·9 to 10 ..	47	7·1	3·0	2·3	1·2	·6	·7	·8	·2	·4	·2	·04	2·6	1·4	1·0	·2	·2	·6
Under 10 ..	48	9·0	3·9	2·6	1·6	·9	1·0	1·2	·3	·6	·2	·03	3·2	1·2	·9	·2	·1	·6

individual colliers, and the only feasible method was that adopted by them spontaneously, namely, to take a rest when they felt that they needed one.

In order to obtain more exact information about the number and duration of the rest pauses taken than can be derived from a study of the individual records, we have split up our 138 observations into three nearly equal groups, according to the wet kata cooling power of the air at the time the work was performed. The average rests observed are recorded in Table IV. It will be seen that the number of voluntary rests was about 7 per hour when the wet kata cooling power was 10 or more, whilst they increased to 9 per hour when it was under 10. The majority of these rests lasted under a minute, and not more than 1 in 10 lasted over two minutes. Their mean duration was 0·7 minute when the cooling power was 10 or more, and 1·0 minute when it was under 10. The involuntary rests differed greatly from the voluntary rests, for they were only about a tenth as frequent, and when they did occur, they lasted on an average about three times longer. Indeed, many of them were over five minutes in duration and some of them over 20 minutes. Arguing from the observed duration of the voluntary rests, we may conclude that the most advantageous rest to take in coal getting is usually one which lasts less than a minute, so there can be little doubt that almost all of the involuntary rests forced on the miners were unnecessarily long, having regard to the relief of fatigue. In so far as they exceeded real requirements, they were more or less wasted, and the longer they were the greater the degree of waste. The rests taken in discussing the work resembled the voluntary rests, in that three-fourths of them lasted less than a minute, so they must have been of greater value than the involuntary rests in relieving fatigue. However, they were not likely to be so valuable as voluntary rests, for these would be taken just when a special need was felt, whilst rests for talking might occur at any time, owing to the interjection of a mate or deputy, whether they were needed or not. It will be seen from Table IV that the number and duration of the rests taken for talking were uninfluenced by atmospheric conditions, so in this respect likewise there was no adaptation to the physical needs of the miners.

The relative value of the three kinds of rest pause in relieving fatigue cannot be predicted; but it can be estimated to some extent by statistical methods. In order to ascertain it we split up all our observations into three nearly equal sections, according as the rest pauses taken were (*a*) mainly voluntary, (*b*) intermediate, or (*c*) mainly involuntary. Each of these sections was subdivided into three groups according to the wet kata cooling power of the air (as in the data recorded in Table IV), and the various rest pauses were averaged. The results obtained are recorded in Table V. From the mean values it can be gathered that when the miners got only 0·2 minute per hour of involuntary rests and 0·3 minute by talking, they spontaneously took 6·5 minutes of voluntary

TABLE V.—*Duration of various rests taken by coal miners.*

Wet kata cooling power.	(a) Mainly voluntary.				(b) Intermediate				(c) Mainly involuntary.			
	Voluntary.	Involuntary	Talking	Total.	Voluntary.	Involuntary	Talking	Total	Voluntary	Involuntary	Talking.	Total.
12 and over ..	5·7	0·0	0·3	6·0	4·7	1·1	1·2	7·0	4·4	5·5	1·7	11·6
11·9 to 10	5·6	0·3	0·4	6·3	6·0	1·0	1·2	8 2	3·5	9·7	2·1	15·3
Under 10	8·1	0·3	0·3	8·7	8·1	2·1	1·2	11·4	6·2	9·9	1·3	17·4
Mean	6·5	0·2	0·3	7·0	6·3	1·4	1·2	8·9	4·7	8·4	1·7	14·8

rest. When, on the other hand, they got 8·4 minutes per hour of involuntary rests and 1·7 minutes by talking, they took only 4·7 minutes spontaneously, or 1·8 minutes less. Hence it is evident that the involuntary and the talking rests, taken together, had some value in relieving fatigue, though not nearly so much as purely voluntary rests.

Grouping together the involuntary and the talking rests under the heading 'non-voluntary,' we see from the Table that their effective value, from the point of view of relieving fatigue, is about a *fifth* as great as that of the voluntary rests. The absolute figure must not, of course, be pressed, but it does strongly suggest the comparative ineffectiveness of involuntary rests. As can be seen from the figures adduced, the rest pauses of the three sections

Character of rests taken.	*Duration of voluntary rests only.*	*Duration of voluntary rests* + $\frac{1}{5}$ *of "non-voluntary" rests.*	
(*a*) Chiefly voluntary	6·5	6 6	6·7 minutes per hour
(*b*) Intermediate	6·3	6·8	
(*c*) Chiefly involuntary	4·7	6·7	

of men, when corrected on this basis, work out to a nearly steady value of 6·7 minutes per hour, and this interval may be regarded as the duration of the *effective* rest pauses taken by the miners.

The most important practical conclusion to be derived from this statistical study lies in its demonstration of the ineffectiveness of involuntary rests. If we are right in concluding that about four-fifths of such rests are wasted, on an average, we may assume that a still larger proportion of the longer rests represent wasted time, so far as regards the elimination of fatigue. Hence the reduction of these long involuntary rests to a minimum is very important on the grounds of efficiency

Summary.

Men engaged (at a day rate) on work of a moderately heavy character such as road making, agriculture, and dock labouring, have been found to take rest pauses from work amounting to about 11 minutes per hour. If the work is of a regular character, the men spontaneously take rests with considerable regularity, usually at about six-minute intervals; but with more varied work the rests become more and more irregular in frequency and duration.

Piece-rate workers employed on work requiring a similar degree of physical energy probably take shorter rests than day-rate workers, but even in them the rests are frequent. The more arduous the work the longer the rests, and in the heavy work of pitch loading they amount to 22—26 minutes per hour, and in rolling tinplates to from 14—28 minutes per hour. The men take similar amounts of rest throughout the working day.

Colliers take rests varying from 7 to 22 minutes per hour, according to the atmospheric conditions under which they are

working. From 5 to 9 minutes of this time is voluntary, each voluntary rest taken usually being of less than a minute in duration The involuntary rests (generally due to lack of tubs) are only a ninth as numerous the voluntary, but they last three times longer. It is calculated that they have only a fifth the value of voluntary rests in relieving fatigue

The colliers take rests with extreme irregularity, owing to the very varied nature of their work It would be quite impracticable to devise an artificial scheme of rest pauses for them.

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INDUSTRIAL
FATIGUE RESEARCH BOARD.

REPORT No. 42.

Rest-Pauses in Industry

(A Review of the Results obtained)

By S. Wyatt, M.Sc., M.Ed.

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PREFACE.

The wide adoption in recent years of the one-break day in industries has almost always been accompanied by the division of the full working day into two work spells of approximately equal length separated by a meal interval of about one hour's duration The most usual number of daily hours worked is eight and a half to nine, and each spell may vary from four to five hours according to the distribution adopted.

At the same time the breaking up of the spells themselves by means of one or more short pauses interpolated at regular intervals has become an increasingly common practice, and much investigation has lately been devoted to its effects. In view of the practical interest of the subject, the Board have thought it desirable to issue the present report, which summarises the knowledge at present available

It will be seen that substantial results have already been achieved, but that nevertheless much investigation and experiment, especially under practical conditions, are still required before the optimum relation between rest and activity for different kinds of work can be precisely determined. In particular, the length and position of the rests desirable on physiological grounds remain to be further explored.

In the opinion of the Board, however, there are strong grounds for thinking that as a general rule, the influence of such rest-pauses is definitely beneficial. In many of the cases tried, the introduction of the system has been followed by an unconscious response on the part of the workers, reflected in an increase in the total output in spite of the reduction in the actual working time, whilst the opinions of the workers themselves, after they have once become accustomed to the change of practice, have usually been favourable.

It should be noted that the increase, or even the maintenance, of total output shown in many of the instances investigated clearly cannot always be expected. As the author points out, in strictly automatic processes, where production depends upon the machine alone, there must necessarily be a loss in output corresponding with the time spent in resting, but a further study of these processes may nevertheless show that, where the work is continuous, rest-pauses are conducive to the well-being of the worker, even though the circumstances do not admit of the improved working capacity on the part of the operative being reflected in increased production. The full beneficial effects of rest-pauses are most clearly seen in operations calling for continuous attention or activity on the part of the worker, and, in these, almost all the evidence available suggests that the practice is one deserving of general adoption, whenever factory conditions permit.

March, 1927.

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REST-PAUSES IN INDUSTRY.

(A Review of the Results obtained.)

By S. WYATT, M.Sc., *Investigator to the Board.*

CONTENTS.

1. INTRODUCTION.

The weekly hours of work (48) at present in vogue in this country, have, in most cases, caused a redistribution of the daily hours of work. In many industries the one-break day is now in operation, involving work-spells of from 4 to 5 hours duration. The opinion is often held that an unbroken spell of 4½ or 5 hours is detrimental to efficiency and the well-being of the worker, and that one or more pauses should be introduced within the spell of work. Investigations, both laboratory and industrial, have already been carried out with a view to determining the effect of rests within the spell of work, and the contents of this report are mainly a summary of the results obtained, together with appropriate comments and considerations for the future.

2. CONSIDERATION OF RESULTS OBTAINED.

(a) *Position of Rests.*

Where rest-pauses have been tried, they have been introduced in most industrial establishments about the middle of the work-spell.

Vernon,[1] for instance, in an investigation on the conditions of work in munition factories, found that in some works the usual custom was to have a break in the middle of the morning and afternoon spells. In America also, the prevailing practice among establishments was to provide a rest-period at similar times.[2] When only one pause a day has been allowed, it has usually been given about the middle of the morning spell, and has been regarded rather as a means of providing an opportunity for refreshment than as a rest.[3] Considerations deciding the position of the rest have been largely empirical, and this procedure must sometimes result in the introduction of rests at times when they are not needed, so that instead of being beneficial, they will only tend to interfere with the swing of work and cause a reduction in output when work is resumed. It is not surprising, therefore, that the effects have sometimes proved unfavourable to production.

An improvement upon this method is suggested by some laboratory experiments carried out by Graf.[4] He introduced rests at different times in work-spells, devoted to the addition of single digits, of one and two hours' duration. In both cases it was found that the most favourable position for the rest was after the second third of the work-period. Although this method is also empirical, it implies a recognition of the fact that the best position for a rest is not necessarily half-way through the spell of work. Theoretically this is the correct scientific method of procedure, though there may be difficulties in applying it under practical conditions.

Before rest-periods are introduced, a careful quantitative investigation of the prevailing conditions of work should be made and a normal curve of output thereby obtained. Such a curve will often show that in each spell of work, output increases first to a maximum, and afterwards falls gradually to the end of the spell.

If a rest is introduced, it should be given at about the time when the output has just reached its maximum[5] (Points A and B Fig. 1.) At this stage working activity is about to decrease, and the recuperative effects of the pause will retard the onset of

[1] "Output in Relation to Hours of Work." Interim Report on Industrial Efficiency and Fatigue, issued by the Health of Munition Workers' Committee 1917 Cd. 8511, p. 25

[2] "Rest-Periods for Industrial Workers" Research Report No 13 of the National Industrial Conference Board, p 25

[3] cf American Report op cit. p. 25 and Vernon, Report No 25 of the Industrial Fatigue Research Board. pp 7 et seq.

[4] "Über lohnendste Arbeitspausen bei geistiger Arbeit." *Psy. Arbeiten.* Vol. VII. No. 4, p 548.

[5] It might be objected that, since output is about to decrease, the subjective factors responsible for this condition already exist, and consequently the pause should be given some time *before* the decrease is observed. Against this it should be pointed out that the anticipation of an expected rest tends to delay the advent of the point at which output begins to decrease, consequently, in practice, no serious harm will be done if the pause is introduced as suggested in the text.

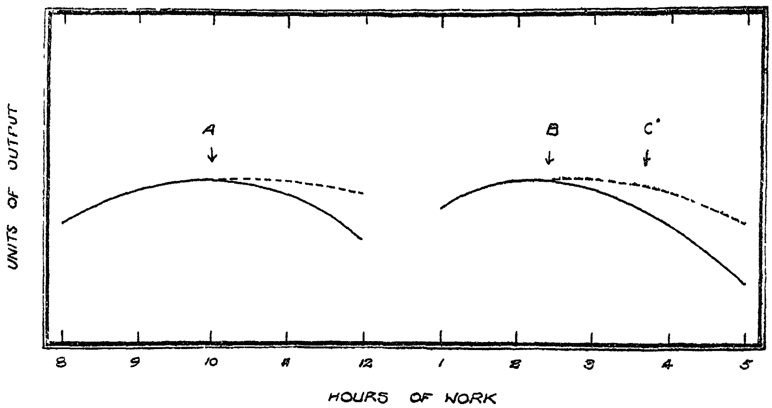

FIGURE 1.—Showing most suitable position of rest-pause in relation to shape of output curve.

factors detrimental to output and tend to maintain working activity at a high level during the remainder of the spell (broken line). After the introduction of the pause, output curves corresponding to the new conditions should be obtained, and if a marked decrease is still noticeable in the latter part of the spell, a second pause should be introduced at the point where output again begins to decrease (e.g., point C, p.m. spell). In this way the greater part of the decrease in output could be avoided and a relatively high efficiency maintained throughout the spell. The original type of curve will, of course, depend upon the type of work, and may be very different from that shown in Fig. 1. In work of a rhythmical nature, for instance, the rate of working often tends to remain at a fairly uniform level throughout the spell,[1] but in work of a monotonous character a decrease in output often occurs about the middle of the spell.[2] It will be found that the most suitable position for a rest-pause will depend upon the nature of the industrial process, and will vary for almost every type of work. Only experimental investigation will determine the most favourable position for each type.

If an investigation of the existing conditions of work is impossible, then the rest should be given after work has been in progress for 2 or 2½ hours. Most operatives, especially those engaged in light repetition work, are able to maintain a high rate of working for this length of time, and the result would almost certainly be an increase in production.

(b) *Length of Rests.*

The length of rest-pauses, like their position in the spell of work, has also been decided by chance rather than by scientific investigation. In America the usual length of rest is found to have been 10 minutes, irrespective of the type of work performed,

[1] Report No 32 of the Industrial Fatigue Research Board, p. 7

[2] cf. Report No. 26 of the Industrial Fatigue Research Board, pp. 28, 30, and 32

but sometimes a rest of 15 minutes is given.[1] Rests of a similar duration are also adopted in some English establishments,[2] although in some cases the length is limited to 5 minutes.

In all activities there are factors, such as incitement, which tend to augment working capacity, and others, such as fatigue, which have an opposite effect. The most favourable pause for the particular kind of work under consideration will conserve as much as possible of the former, and at the same time eliminate as much as possible of the latter. A brief pause from activity may cause a considerable loss of swing and incitement, and only a slight recovery from the effects of fatigue. In such a case the net result of the rest will probably be a reduction in output. Too long a rest may be equally unfavourable, because it may be more than enough to dispel the factors which have been impeding working capacity.[3] The aim is clearly to strike the happy mean, and a procedure based upon guess-work will be wholly inadequate in this respect. Investigations on the effect of rests of different length, given in the most suitable position, appear to be a missing feature of industrial research, but the results of a number of laboratory experiments are available.

Graf,[4] for instance, in a work period of one hour devoted to mental addition introduced rests of $\frac{1}{2}$, 2 and 5 minutes' duration after 40 minutes. All the rests were found to be favourable, but the most beneficial was the 2 minutes' rest. Rests of 1, 3, 5, and 10 minutes were also given after 80 minutes' addition in a work period of 2 hours. In this series of experiments the most beneficial rest was found to be 5 minutes, although an increase in output was obtained in each case. Amberg,[5] also in a laboratory investigation, found that a pause of 15 minutes introduced half-way through a work-period of one hour had an unfavourable effect on output, while a pause of 5 minutes had a small but favourable influence. Hylan and Kraepelin[6] further state that when a rest is taken, the conditions during the first 5 to 10 minutes of the pause are favourable for the resumption of work, but during the next ten minutes become less favourable, after which an improvement again takes place. They explain these results by assuming the

[1] "Rest-Periods for Industrial Workers," op. cit., p 25.

[2] Report No 25 of the Industrial Fatigue Research Board, pp. 7 et seq

[3] An interesting example of the unfavourable effect of rests was obtained in connection with the marking of clinical thermometers at the National Physical Laboratory In this process the output on days of continuous work was compared with that obtained on days when rests of 15 and 30 minutes were allowed after approximately one and two hours work respectively

The results showed that the time taken to complete a unit of output was least on the days of continuous activity.

In this case the length of the rests appeared to be excessive, and since the amount of fatigue produced by activity was almost negligible, the rests only served to cause a loss of incitement and practice. (From an unpublished report.)

[4] Otto Graf. op. cit.

[5] "Über den Einfluss von Arbeitspausen auf die geistige Leistungsfähigkeit" *Psy. Arbt.* Vol. 1. p. 300.

[6] "Ueber die Wirkung kurzer Arbeitszeiten." *Psy. Arbt* Vol. 4, pp. 454–494.

loss of incitement due to the pause is small at first, but afterwards increases rapidly. A point occurs at which the progress of recovery is surpassed by the loss of incitement, after which the recuperative process becomes dominant. Phillips[1] too, in a carefully conducted series of experiments, found that the beneficial effect of a rest was not proportional to its length, and similar results have been obtained by Heuman,[2] Oseretzkowsky and Kraepelin,[3] and Lindley.[4]

Under industrial conditions, it has been found that in some cases, even though the rest brings about an increase in the rate of working, this increase is insufficient to compensate for the actual productive time lost during the rest When this occurs, either the rest may be too long or the conditions of work may not justify the introduction of a rest. Activities in which the mechanical element is predominant, or in which the rhythmical factor predominates, are examples of such conditions, but in repetitive handwork the introduction of a rest will often have a favourable effect upon production. Nevertheless, the absence of any noticeable objective advantage, following upon the introduction of a rest, does not necessarily imply that a pause is undesirable and should be discontinued. In such cases the rest may have a favourable effect upon the workers, but the actual extent of this effect is often difficult to measure. Employers who are prepared to give rest-pauses a trial in their establishments, should begin by introducing a rest of five minutes' duration about the middle of the spell of work. This arrangement should be continued for about three months, and the general effects noted. The length of the pause should then be increased by two minutes and the effects observed over another three months. Further trials with successive increases of two minutes in the duration of the pause would finally show the most favourable length of rest under the given conditions of work.

(c) *Distribution of Multiple Rests.*

In many processes, instead of a comparatively long rest about the middle of the spell, the introduction of several rests of shorter duration may be found advisable. When the point of maximum output occurs early in the spell, and is followed by a decline in the rate of production, the introduction of several rests will usually be beneficial. Since the recuperative effect of a rest is partially dependent upon its relation to the quantity of work already performed, it will probably be desirable to increase the duration of each successive rest throughout the spell of work, or, conversely, to give rests of the same duration with increasing frequency as work proceeds. Few experimental results bearing on this question have yet been obtained, but the matter is certainly worthy of investigation.

The advantages of a suitable distribution of rests are illustrated by the work of Taylor[5] in connection with the handling

[1] " Mental Fatigue," by Gilbert E Phillips. Sydney. 1920

[2] " Über die Beziehungen zwischen Arbeitsdauer und Pausenwirkung " *Psy Arbeiten.* Vol IV, p. 538.

[3] " Über die Beeinflussung der Muskelleistung durch verschiedene Arbeitsbedingungen " *Psy. Arbeiten* Vol III, p. 587.

[4] " Über Arbeit und Ruhe " *Psy. Arbeiten.* Vol. III, p. 482.

[5] " The Principles of Scientific Management." N.Y. 1911. pp. 41–64.

of pig-iron. Although his experiments fail to show the actual effect of introducing rest-pauses, because they refer to a selected group of workers whose rate of payment was also increased, they nevertheless are useful in suggesting the possibilities of alternating work and rest-periods in heavy muscular work By varying the duration of the alternating work and rest-periods, Taylor found the most suitable conditions for loads of different weight. In an investigation connected with the assembling of bicycle chains, in which the workers were allowed a rest of five minutes every hour, Vernon found that, although the rests absorbed 7 per cent. of the working day, the output began to increase immediately after the introduction of the rests, and finally attained a level which was 13 per cent. greater than in the pre-rest period Somewhat similar results from introducing rests of similar duration and distribution were obtained from girls employed in inserting discs in small metal caps. In connection with these results, Vernon points out that the observed increase in output due to the rests was generally greater than in other cases investigated in which a single rest of 10 minutes was introduced about the middle of the morning spell, and he attributes the increase in question to the more liberal allowance of rests.[1]

Results bearing on the same question have been obtained from a group of workers engaged in the process of emptying and filling a series of presses.[2] Each press, after being filled, had to be left under hydraulic pressure for 35 minutes, during which time the other presses in the series had to be emptied and filled. The management calculated the number of presses to each series, which would allow the work to be done in 35 minutes at a reasonable pace, but the workers on their own initiative adopted another method. They worked with a rapidity so organised that the series of presses was emptied and filled in less than 25 minutes, after which they rested for 10 to 12 minutes until it was time to begin again.

This example is interesting, because it shows that in this particular case the operatives preferred to work at maximum speed for short periods followed by suitable rests, rather than at a slower but continuous rate throughout the spell. By taking rests which amounted approximately to 3 hours per day, they were able to do the same amount of work, presumably with greater comfort, as that accepted as suitable in spells of continuous activity.

An interesting example of the effect of varying the distribution of rests is quoted by E. D. Jones.[3] In a particular job it was

[1] Report No. 25 of the I.F.R.B., p. 7.

[2] "Output in Relation to Hours of Work." Interim Report on Industrial Health and Efficiency, issued by the Health of Munition Workers' Committee. 1917. Cd. 8511. p. 16.

[3] "The Administration of Industrial Enterprises." N.Y. 1919. pp. 221–2.

found that when the workers took spontaneous rests they produced 16 pieces per hour; when working 25 minutes and resting 5 they produced 18 pieces; when working 17 minutes and resting 3 they produced 22 pieces; and when working 10 and resting 2 they produced 25 pieces per hour. Thus for a given fraction of the total time devoted to rest-pauses, the output increased with the frequency of the pause, and further experiments might have revealed even more favourable conditions. Such experiments illustrate the need for trying many different combinations of work and rest before the best conditions can be determined.

The importance of a suitable distribution has also been shown in laboratory experiments. Burnett,[1] for instance, has attempted to determine the effects of different arrangements of rests in connection with workers engaged in repetition work. The results showed that three rests of 5 minutes distributed at equal intervals throughout a work-spell of 3 hours given twice a day, were slightly more favourable than a rest of 15 minutes given in the middle of each spell Both these arrangements, however, were inferior to days of unorganised rests, but the number and duration of the pauses taken in the latter case are not given.

In another investigation[2] it was found that two rests of 5 minutes, each introduced after each 50 minutes in a spell of 2½ hours, gave an increase in output, which was almost twice the increase obtained when only one rest of 10 minutes was allowed in the middle of the spell.

Vernon[3], on the other hand, working with a dynamometer, found that when rest-periods of the same relative duration to the work-periods were taken at intervals of 2½ secs , 30 secs., 40 secs., 2 mins. and 5 mins., they had very little effect upon the capacity for work.

The above considerations emphasise the importance and complexity of questions connected with the most suitable distribution of rests. The divergence of opinion held by industrial authorities only seems to illustrate the need for further experiments on rest-pauses. Thus we find Gilbreth[4] remarking that " In most work more output can be achieved by applying one's self steadily for short periods, and then resting, than by applying one's self less steadily and having no rest-periods," while a German writer[5] states that, " A shorter work day with more intensive work secures a greater output than a longer day with

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[1] Report No. 30 of the Industrial Fatigue Research Board, p. 10.
[2] Report No 32 of the Industrial Fatigue Research Board, p 34
[3] Report No 29 of the Industrial Fatigue Research Board, p. 42.
[4] " Fatigue Study," p 41.
[5] Ernst Bernhard, " Hohere Arbeitsintensitat bei kurzerer Arbeitszeit " Leipzig. 1909. p. 43.

rest-pauses." Each of these statements may be true for particular kinds of work, but investigations are needed before either can be accepted generally.

(d) *Rests Necessary for Complete Recovery.*

A suitable alternation of work and rest will often enable activity to be continued for long periods of time without any decrease in efficiency. In such cases the periods of rest are sufficient to dispel entirely the effects of fatigue produced by work. The heart, for instance, will continue to work throughout life without any accumulation of fatigue. In all forms of activity, such rhythms of work and rest exist

Thus, Maggiora[1] showed that when the middle finger was made to lift a weight until further contractions were impossible, a rest of 2 hours was necessary for complete recovery. If, however, only half the number of contractions were made, the length of rest necessary for complete recovery was reduced not to one-half but to one-quarter. Thus the need for rest is progressive, and as the duration of work is prolonged, the time necessary for complete recovery increases progressively.

Rivers and Kraepelin[2] again showed that a rest of one hour, following half an hour's intensive mental work, was not quite sufficient to eliminate entirely the effects of fatigue.

Further results were obtained by Phillips,[3] who found that one minute's work in multiplication must be followed by a rest of 4 minutes before working capacity is restored to its original level.

Scientifically, these results are suggestive, and indicate that for each kind and duration of work, a period of rest exists which is able to produce complete recovery from the effects of activity. Practically, however, they have little possible application, since the alternation of such periods of work and rest, although enabling work to be performed at the maximum level of efficiency throughout the day, would cause a reduction in total output due to the excessive proportion of rest to work. The results so far collected under industrial conditions suggest that the rests which are too numerous and prolonged, although capable of completely eliminating fatigue, will also cause a reduction in total output, because of the shorter time worked.

There is reason to believe that the rate of restoration of working capacity during rest is greatest in the early stages of the pause, but progressively decreases as the pause proceeds.[4] If this is so, each unit of time during the pause is economically less valuable than the one preceding it, and the extension of the pause beyond a certain point becomes productively undesirable.

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[1] "Fatigue," by A. Mosso English translation by M. and W. B. Drummond. N.Y. 1915.

[2] "Ueber Ermüding and Erholung." *Psy. Arbeiten.* Vol. I, p. 627.

[3] "Mental Fatigue." Sydney. 1920.

[4] Phillips, op. cit., p. 93, et seq.

(e) *Method of Using Rest-Pauses.*

Investigations on rest-pauses have been almost entirely confined to questions connected with their length and position. The method of using the rest, although of equal importance, has been practically ignored. It is conceivable that the beneficial effects of a rest of suitable length and position may be more than neutralised by the way in which it is spent, and many of the conflicting results obtained are partially attributable to this cause

In some industrial establishments,[1] a cup of tea is supplied to each operator during the rest, and often a little food is taken at the same time. This arrangement is particularly beneficial when the spells of work are from 4 to 5 hours' duration, and the intervals between meals accordingly very long. In some American establishments,[2] regular provision for recreation, exercise, and ventilation has been made and has been appreciated by the workers. Farmer[3] again found that it was advisable to allow the workers to leave their seats, wash, walk about and talk. In another American establishment,[4] the records of a chain-manufacturing plant showed that the general health of the workers having rest-periods, during which they took physical exercise under an instructor, had been greatly improved.

Vernon, working with a dynamometer, showed the importance of a change in posture during the rest-periods. He found that when the subjects of the experiment remained motionless during the rest, the total amount of work done was always less than when no rests were taken ; but if the subject bent his shoulders back and moved his arms about, these postural changes caused a considerable reduction in the fatigue effect, so that the total amount of work done was from 2 to 14 per cent. greater than when no rests were taken. Also, the strength of pull remained at a constant level throughout the experiment (88 minutes). Whereas without the changes in posture, it continued to decrease throughout the greater part of the experimental period. The favourable effects produced by the change in posture were attributed by Vernon to changes in the circulation.[5]

Some laboratory experiments bearing on this subject have been carried out by S. C. Jackson,[6] who introduced a rest-pause of 15 minutes in the middle of a work spell of two hours devoted

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[1] See, for instance, " Output in Relation to Hours of Work " in Interim Report on Industrial Health and Efficiency Cd 8511, p. 25.

[2] Public Health Bulletin, No. 106, p. 176.

[3] " An experiment on the introduction of rest-pauses." *J. National Inst. of Indust. Psy* Vol. I, No. 3, p. 90.

[4] " Rest-Periods for Industrial Workers." Report No 13 of the National Industrial Conference Board, p. 7

[5] Report No 29 of the I F R B , pp 43, 46

[6] From an unpublished Report of an investigation carried out in the Psychological Laboratory, University of Manchester. (In the rest with complete relaxation, the subjects sat quietly in easy chairs. In the uncontrolled rest, they usually sat and smoked and indulged in light conversation.)

to simple addition Three subjects took part in the experiment, and the results under consideration were obtained after the effects of practice had been eliminated. The rest was spent in different ways, and the percentage increase in output over a period of continuous work was :—

Nature of rest.	*Gain in output.*
Complete relaxation	9·3
Uncontrolled rest	8·3
Music	3·9
Tea	3·4
Walk	1·5

The greatest increase occurred when the subjects were allowed complete relaxation in easy chairs, and the least beneficial form of rest was the walk, chiefly because the subjects were unable to settle down for some time after work was resumed. These results are, of course, merely suggestive, but they indicate the importance of determining experimentally the most suitable form of rest under industrial conditions.

Kraepelin also gives an account of some laboratory experiments in which two women performed the task of threading beads as quickly as possible. An attempt was made to determine the effect of various interpolated activities upon threading ability. Thus the subjects first threaded beads for 10 minutes, then the next 30 minutes were devoted to either (*a*) complete rest or (*b*) gymnastics or (*c*) mental addition or (*d*) memorising nonsense syllables, after which beads were again threaded for 10 minutes. The results showed that memorising, compared with the complete rest, had a favourable effect on the threading process, but the effect of adding was slightly unfavourable. After gymnastics both subjects showed a decrease in threading ability. On the whole, the threading process was found to be only slightly influenced by the interpolated rest or activities. Probably more significant results would have been obtained if the duration of the threading process in relation to the interpolated activity had been increased.[1]

In general, it may be said that the manner of using the rest should be dependent upon the character of the previous work. Sedentary workers will benefit by the change of posture and movement, while those engaged in heavy muscular work will appreciate an interval for relaxation and rest. Operatives who are compelled to stand while working will appreciate an opportunity to sit during the pause, while those who work in a sitting posture will usually prefer to stand or walk about. Further, many industrial occupations can be performed in either a standing or sitting position, yet very few attempts are made to introduce such variations in postures under industrial conditions. Scientific evidence on this aspect of rest-pauses is almost non-existent, and a wide field for inquiry awaits the industrial investigator.

[1] Arbeitpsychologische Untersuchungen. *Zeits. f. d. ges. Neurologie u. Psychiatrie.* Vols. 70 and 71, 1921).

(f) *Effect on Different Individuals.*

Several investigators have drawn attention to the fact that the introduction of rest-pauses may have different effects upon different individuals. For instance, when rests of 10 minutes' duration were introduced in the middle of the morning and afternoon spells in the American metal-working industry,[1] it was found that in the case of some workers output decreased, but with others the total output was maintained or increased. In an investigation on handkerchief-folding the introduction of a pause produced increases in the rate of working in different individuals varying from 2·7 to 6·5 per unit.[2] Vernon[3] also found that the effect of rests was greatest in the case of the less efficient workers, the quicker workers not being benefited to the same extent.

Similar differences have also been observed in laboratory experiments. Thus Lindley[4] showed that while rests of 5, 15, 30, and 60 minutes introduced between two work-periods of 30 minutes each gave an increased output in the second half-hour in the case of two subjects, a decrease was observed in the output of a third worker.

In practically all laboratory investigations on rest-periods there have been large individual differences in the results obtained. In some persons, a pronounced increase in output has resulted, but in others, the effects have been less favourable or even negative. Such results are only to be expected, since individuals vary in their susceptibility to the effects of work, and consequently in their need for rest. The determination of the most suitable rests for any given worker is essentially an individual problem, and would require a detailed study of the curve of work for each individual. It would be found that a slightly different arrangement of rest and work would be necessary for each worker if maximum efficiency is to be attained, but the practical difficulties involved in the adoption of such a procedure would, of course, be insuperable. Further, the taking of rests at different times would be opposed to the beneficial effects accruing from mass effort, since, as a rule, a person rests better when all the others are also resting, and works better when others also work.

(g) *Relation of Rest-Pauses to Nature of Work.*

Rest-pauses have been shown to be particularly beneficial in repetition work of a monotonous character. Thus the introduction of a rest of ten minutes about the middle of the spell of work in the processes of handkerchief folding, handkerchief ironing, and stamping-out cigarette tin lids produced an increase in the rate

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[1] U S Public Health Bulletin, No. 106, pp. 175–199.
[2] Report No 32 of the I.F.R.B.
[3] Report No. 25 of the I F R B., p. 13.
[4] Op. cit., p. 488.

of working varying from 1·5 to 8 per cent.[1] Vernon also observed increases in output of 13, 5, 8, and 11 per cent. in four characteristic repetitive processes after the introduction of a rest of 10 minutes about the middle of the morning spell of work.[2] In long continued monotonous activities, inhibiting processes diminish the capacity for work, but the introduction of suitable rests tends to neutralise the effects of monotony, and the relief obtained is usually reflected in a higher output Since the present tendency in industrial developments is towards standardisation and an increase in the amount of repetition work, the value of rests as a means of alleviating the effects of monotony will become increasingly important.

Processes involving constant attention and judgment, such as inspection and telephone work, are also, as a rule, favourably affected by suitable rests. These processes are not necessarily monotonous, but are often fatiguing because of the constant strain on attention and the higher mental processes. In such cases rest-periods provide opportunities for recuperation. In 1907 an investigation into the conditions of work of telephone operators in Toronto resulted in a recommendation for the adoption of rest-periods after each two hours of work.[3]

Operatives who are required to adopt either a continuous sitting or standing posture usually find rest-pauses very welcome and beneficial. Long continued activity in the same posture often gives rise to unpleasant muscular pains and cramps which undoubtedly tend to reduce efficiency. It has been suggested by Vernon[4] that a change of posture promotes the circulation of the blood through the fatigued muscles, with the result that the fatigue products are removed more speedily and efficiency in consequence increased.

Heavy work also is usually favourably influenced by the introduction of rests. In general, the greater the amount of effort expended, the more numerous should be the pauses (cf., Taylor's investigation mentioned on p. 6).[5]

The speed of industrial operations is another factor which should be considered in relation to rests. In many cases the pace of the machinery imposes an additional strain upon the workers, and if rests are not allowed, the rate of production usually decreases rapidly as work proceeds. Industrial conditions which require a working rate in excess of the natural rhythms

[1] Report No 32 of the I F R.B , p 9.

[2] Report No. 25 of the I F R.B., pp 7–9.

[3] " Rest-Periods for Industrial Workers," op. cit. p. 10.

[4] Report No. 29 of the I.F R B., p. 52

[5] An account by Vernon and Bedford of rest-pauses taken under industrial conditions by men engaged on heavy muscular work is in course of publication (Report No. 41 of the I.F.R.B.).

of the body are conducive to increased fatigue, and, if unavoidable, their effects should certainly be alleviated by means of suitable rests. It will be found that different conditions of work demand rests of different frequency and duration, and the most suitable arrangement must be experimentally determined for each type of work.

The quantitative effects of rests will obviously be dependent upon the relative importance of the mechanical element in production. In a purely automatic process, for instance, the introduction of a rest will cause a decrease in output proportional to the length of the rest, and the beneficial effects of the pause will be wholly subjective As production becomes increasingly dependent upon the activities of the worker, the favourable effects are proportionately reflected in the amount produced, and are usually at a maximum in purely manual operations. An illustration of this principle is provided by the investigations conducted by Vernon, who found that in the purely manual process of handkerchief folding, the introduction of a rest produced an increase in output of 4·4 per cent. while in the semi-mechanical operation of hemstitching, a similar rest gave rise to a decrease in output of 3·4 per cent.[1]

(h) *Team-Work with Rest-Pauses.*

The possibility of introducing rests without involving a stoppage of the machines is a feature of industrial work which has received little consideration. One of the objections levelled against rest-pauses is that they often involve a cessation of productive activity, and consequently a loss in output. Loveday,[2] however, showed that in the press-room of a boot and shoe factory, an increase in output of almost 50 per cent. could be obtained by assigning three girls to presses formerly worked by two, so that each girl rested for 20 minutes every hour. By this means, the machines were enabled to work continuously, and the increase in output was obtained without the addition of new machines or an increase in the mechanical cost of running. True, an increase of 50 per cent. in the number of operatives employed was also necessary, but they were enabled to work more comfortably and with less fatigue.

A similar method was also adopted in a bottle works where the presses were worked by one man and two boys. Additional boys were engaged so that each boy could work 40 minutes and rest 20. By this means it was possible to speed up the machine without increasing the fatigue of the operatives.[3]

In systems such as these, if the increase in output is proportional to the increased number of operatives employed, the

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[1] Report No 25 of the I F.R B , p. 12.
[2] Report No. 10 of the I F R.B., p. 29.
[3] Quoted by Miles in the *Nat. J. Ind. Psy.* Vol. I, No. 7.

cost of production will be decreased because the overhead charges remain the same. Team work, then, in certain cases, may be decidedly beneficial since it enables work to be done with less fatigue, provides employment for a greater number, and reduces the cost of production. Probably production would be still further increased if the operatives, instead of resting during the 20 minutes, were employed on different but lighter work. A change of activity is sometimes quite as beneficial as an actual rest, and work organised along these lines would undoubtedly give satisfactory results [1]

(i) *Objective Effects.*

The majority of results obtained in connection with the introduction of rest-pauses show that in almost every case the hourly rate of production has been increased. The increase in question has been shown to be due to (*a*) an increase in the rate of working,[2] and (*b*) a reduction in the number and duration of unauthorised rests.[3] From the practical standpoint, however, an increase in the rate of working is not sufficient to warrant the continuation of rests within the spell of work ; the employer is primarily concerned with the effect on *total* output. When considered from this standpoint, the effect of rests may be regarded as satisfactory. In the American inquiry,[4] for instance, in only one case was it stated that the introduction of rests had led to a decrease in total output The investigations of Farmer,[5] Vernon,[6] and Wyatt[7] also gave favourable results.

In the course of an investigation into the conditions of work in the German textile industry,[8] in which the hours of work were from 7.15 to 5.45 with a breakfast pause at 9.30, a dinner break from 12 to 1, and an afternoon pause at 3 30, it was found that the morning and afternoon pauses had a distinctly favourable effect on output. The output observed (expressed as a percentage of the daily average) was as follows :

Process.	7.15–9.30	9.30–12.0	1.0–3.30	3.30–5.45
Ring-spinning ..	..23·9	24·9	23·5	27·7
Fine flyer-spinning	..17·6	26·5	26·5	28·2
Coarse flyer-spinning	..19·1	26·8	24·1	22·6

During the pauses at 9.30 and 3.30 the operatives either (*a*) allowed the bobbins to run full and then replaced them as quickly as

[1] For the results of experiments showing the effects of changes of activity see Report No. 26 of the I F R B , and J Nat Inst Ind Psy

[2] See, for instance, Report No 32 of the I F R B (Appendix I).

[3] cf. Report No. 32 of the I F R B , pp. 17–19

[4] " Rest-Periods for Industrial Workers " op cit. pp 19–20.

[5] J Nat. Inst. Ind. Psy. Vol I No. 3

[6] Report No. 25 of the I F R.B

[7] Report No. 32 of the I F R.B.

[8] Marie Bernays : " Untersuchungen Über die Schwankungen der Arbeitsintensität wahrend der Arbeitswoche und während des Arbeitstages." Leipzig. 1912. pp. 285 et seq.

possible after the pause or (*b*) continued to work very slowly or (*c*) allowed the machine to look after itself for 5 or 10 minutes. In most cases the operatives sat during the pause and always took some food, usually coffee but sometimes beer and rolls.

An interesting arrangement of rest and work periods exists in a Yorkshire worsted weaving factory, where the manager is firmly convinced that it is undesirable and uneconomical for the operatives to work for more than two hours without a break. He has accordingly introduced the following distribution of hours of work, which has been in vogue for several years.

7.0 — 8.30	First spell.
8.30— 9 0	Breakfast interval
9 0 —10.45	Second spell.
10.45—11 0	Rest
11 0 —12.45	Third spell.
12.45— 1.30	Dinner interval.
1.30— 3.15	Fourth spell.
3.15— 3.30	Rest.
3.30— 5 0	Fifth spell.

During the rest-pauses, the engine is stopped and the operatives are free to do as they like. Most of them spend the time in the picturesque grounds surrounding the factory, and the pauses are much appreciated and never abused. From the standpoint of production the manager maintains that the results are superior to those obtained before the rests were introduced.

In general, it may be stated with confidence that in all forms of repetitive handwork, the introduction of suitable rests will result in a total increase in production varying from two to five per cent. It is frequently found that the introduction of suitable rests not only increases output, but also has a favourable effect upon the quality of the work done. As a rule, the qualitative effects are much more difficult to measure than the quantitative, and consequently the results obtained in this connection are very meagre. It was, however, stated in the American inquiry,[1] that the work done during the last hour of the day in a printing establishment was of very little value, but after the introduction of a rest of 10 minutes in the morning and afternoon a marked increase in accuracy was observed. In an investigation on handkerchief ironing[2] it was found that the quality of the work during the latter part of the afternoon was improved after the introduction of a pause.

Frequently the quality of the work is just as important as the quantity, and in future investigations both these features of output should be considered.

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[1] " Rest-Periods for Industrial Workers " op. cit. p. 24.
[2] Report No. 32 of the I.F.R.B , p. 11.

(j) *Subjective effects.*

Although the actual increase in output following the introduction of rests may be comparatively small, it is probable that the increase in contentment alone is sufficient to justify the system. Very few workers can look forward with interest and enthusiasm to an unbroken work-period of 4½ or 5 hours, but the knowledge of an expected rest about half-way through the spell makes the task appear less overwhelming and creates a more buoyant attitude towards the work. This change in attitude is sometimes reflected in the output preceding the pause, and has been particularly prominent in laboratory experiments. For instance, some experiments on link-assembling[1] as performed in the manufacture of cycle chains in which three subjects took part showed that when a rest of 10 minutes was given in the middle of a work-period of 2½ hours, the increase in output in the period following the rest (compared with a continuous series) was 5.3 per cent while in the period prior to the rest there was an increase of 3·8 per cent. Graf[2] also found that not only is the output *after* the rest increased, but an improvement is also noticeable *before* the rest occurs. Thorndike[3] has asserted that work without rest decreases efficiency because it is less satisfying, causes the zest of novelty to be lost, produces ennui, and imposes certain deprivations such as lack of physical exercise and social intercourse May Smith[4] also is inclined to think that some of the advantages of rest are of a psychological character. " We can face with equanimity, and even with enthusiasm, a period of two hours work with the prospect of a rest, but to look forward to four or five hours work unbroken is likely to damp the enthusiasm of even an ardent worker."

As the result of experiments in mental addition, in which the subjects worked throughout with maximum effort, Grunthal[5] found that the decrease in the rate of working after the first 15 minutes of work was greater in a work period of one hour than in one of half that length. He accordingly concludes that the longer work-period has a damping effect upon the inclination to work, which, with the accompanying affective state, is responsible for the greater decrease in the rate of working in the longer work-period. The difference in the attitude of subjects towards work-periods of different length was also shown by the results of experiments in link-assembling.[6] Work-periods of 2½ hours and 30 minutes' duration were given on alternate days and the output for each five minutes during the first 30 minutes of work in the 2½ hours test was compared with the output at corresponding times

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[1] Report No. 32 of the I.F.R B Appendix I.

[2] Graf. op. cit.

[3] " The Curve of Work and the Curve of Satisfyingness " J. of App. Psy. Vol. I. 1917. pp. 256–7.

[4] Report No. 22 of the I.F.R.B. p. 19.

[5] " Über den Einfluss der Willenspannung auf das fortlaufende Addieren." *Psy. Arbt.* Vol. VII. No. 3. p. 483.

[6] Report No. 32 of the I.F.R.B., p. 37.

in the shorter test. It was found that, on the average, the output in the shorter test was 4 per cent. higher than the output during the first 30 minutes in the longer test.

Some interesting experiments, for the purpose of determining the readiness to resume work after a pause, are described by Zimmermann.[1] He introduced pauses of 1, 5, and 10 minutes, after a work-period of 15 minutes (addition). In some cases the duration of the expected pause was known, but in others it was unknown. He found that with a pause of 1 minute, the output when work was resumed, was significantly lower when the duration of the pause was unknown. A similar, but smaller, effect was observed with a pause of 5 minutes, but with a 10 minutes' rest the difference had entirely disappeared. He claims that these results show the influence of expectation on output due to rest, and states that the pause causes a total relaxation of the will, which, when the duration is known, prepares itself for the moment of resumption.

When the rest is very short (e.g., 1 minute) and work has to be resumed unexpectedly, Zimmermann states that the relaxed conditions of the will and general state of unpreparedness, together with the accompanying feeling of displeasure due to the surprise, have an inhibiting effect upon activity. If, on the other hand, the rest-pause is longer, but its duration still unknown, the subject feels more and more that he will shortly be expected to resume work, and consequently his readiness increases. As a result, this difference between the effect of known and unknown rest-pauses becomes smaller with their duration. In general, therefore, it appears that in the case of pauses of unknown duration, the readiness to resume work is least immediately after work ceases, but is restored to the normal level when the length of the pause is approximately 10 minutes. When the duration of the pause is known, the subject adjusts himself to the conditions and is in a state of preparedness when he believes the time for resumption is approaching.

Another subjective effect connected with the introduction of rest-pauses is the time required for complete adaptation to the modified conditions. Vernon,[2] for instance, showed that in the case of bicycle-chain workers, a period of 6 months was necessary for the girls to become adapted to the new conditions of work, and a similar phenomenon was observed in the case of women employed in a boot factory. Results of a similar nature were also obtained in American metal-working establishments.[3] In this respect, the response to rest-pauses is similar to the process of adaption which has been observed after a reduction in the weekly hours of work.[4]

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[1] "Über Arbeitsbereitschaft" *Psy. Arbeiten.* Vol. 8, p. 414.
[2] Report No 25 of the I F.R B , p. 11.
[3] Public Health Bulletin No. 106. p. 174 et seq.
[4] Report No 6 of the I F R.B.

The adaptation process is probably largely unconscious and physiological in nature, and appears to be due to a gradual modification in the accumulation and utilisation of energy within the body. As Vernon points out, it is important that manufacturers should realise the slowness of the adaptation process and not be discouraged by the absence of an immediate increase in output Before arriving at a definite decision, a trial period of at least three months should be allowed.

(k) *Objections and Difficulties.*

Frequently, when the introduction of rests has been suggested in connection with industrial operations, opposition to the proposal has been forthcoming from the persons concerned. Employers, for instance, who are often primarily interested in efficiency, have said that in most industrial work so many interruptions to activity must necessarily occur, due to fluctuations in the supply of material, repairs, and the like, that additional pauses are unnecessary. Many such pauses certainly do occur, but often at unsuitable times when the worker does not desire or require a rest, so that they are conducive to worry, irritation and general uneasiness rather than to composure and rest.

In most industrial operations, the operatives normally pause at frequent intervals throughout the day. Vernon[1] has shown, for instance, that men engaged in hand-tapping fuses took, on the average, 7 to 9 minutes of voluntary rest-pauses in all except the first hour of work Tin-plate workers in an 8-hour plant also took from 12 to 14 minutes' rest each hour [2] Presumably, the workers find such pauses from activity necessary and beneficial, but it would probably be better if these unauthorised rests were allowed to coalesce so as to form one or more officially recognised breaks. This is suggested by an investigation connected with work on stamping-presses, wherein it was shown that an authorised and expected rest of 10 minutes was superior to enforced and irregular stoppage[3] of the same total duration ; the actual difference in terms of increased output being 4·6 per cent.[3]

In some processes, such as soldering and chocolate covering, it is conceivable that the soldering irons and chocolate solution may cool during the rest-period, and require re-heating when work is resumed. In such cases pauses may be undesirable, yet if suitable precautions are taken the difficulties should easily be overcome.

A difficulty which sometimes arises, especially in large industrial establishments, is the lack of facilities for the operatives

[1] Final Report on "Industrial Health and Efficiency." Health of Munition Workers Committee. 1918. p. 161. Cd. 9065.
[2] Report No. 1 of the I.F.R.B., p. 10.
[3] Report No 32 of the I.F.R.B., p. 27.

during the rest-period. In most cases, considerable value can be derived from the rest even when the operatives remain in the work-room during the pause from activity, but when there are hygienic and disciplinary objections to this procedure, and no rest-rooms are available, the problem becomes rather difficult. When the provision for resting is limited and a large number of operatives are employed, the latter are sometimes allowed to use the rest-room in successive groups.

Another objection to rest-periods sometimes advanced by employers is the abuse of the duration of the rest allowed. In some cases it is said that the operatives stop work before the scheduled time and afterwards fail to re-start promptly. In well-organised departments, however, such extensions of the pause do not occur.

Again, the operatives, especially those who are paid on a piece-rate basis, are sometimes unfavourably disposed towards rest-pauses They think that the enforced inactivity during the rest will mean a decrease in wage at the end of the week, and the existence of this belief considerably reduces, if it does not entirely neutralise, the recuperative value of the rest. In many cases they prefer to stop work earlier rather than rest during work. As has been already stated, however, the value of a rest depends upon its position in the period of work, and so the same length of rest given at different points in the progress of work will not have the same recuperative value, but must be proportionately increased as work is prolonged. Thus time taken from the end of the day will probably not have the same favourable effects as a rest of equal duration introduced when a decrease in working capacity first becomes noticeable. Some establishments have overcome this objection by paying a time-wage during the periods of rest.[1] Almost all the results obtained in connection with the introduction of rest-pauses under industrial conditions refer to workers paid on a flat piece-rate basis. A clearer indication of the effects of rests would be obtained from workers who are in receipt of a time wage. In such cases the disturbing effect produced by interfering with the economic incentive to activity will be absent, and the general attitude towards the wage question will remain appreciably the same before and after the introduction of the pause. It is regrettable that data relating to the effect of rests have not been obtained under such simplified conditions.

From the psychological standpoint, rests have been said to interfere with the swing and rhythm of work, and to be responsible for a reduction in output when work is resumed. In some processes this is certainly the case, but, as a rule, the previous high rate of working is quickly attained and often exceeded.

[1] See, for instance, " Rest-Periods for Industrial Workers," op. cit., p. 39.

Obviously, the unfavourable effects of a rest will depend upon the kind of activity and the number, duration, and distribution of the rests, and these objections can be removed by a scientific investigation of rests in relation to the nature of the work performed.

The conservatism, fixed habits of work, and dislike of innovations, which are characteristic of most industrial workers, frequently present difficulties to the introduction of rests. In such cases pauses should be suggested by the management when it is apparent that the workers would appreciate a rest. For instance, operatives who originally ridiculed the idea of a pause gladly accepted the suggestion when made by a tactful manager on a particularly hot day in summer. From that day rest-pauses have been continued and found to be beneficial both to the operatives and the management.

In industrial investigations on the effect of rest-pauses, the results have often been obscured by the simultaneous modification of other factors in the conditions of work, and the utmost precaution is necessary if the effects of rests are to be accurately determined. Even when the introduction of a rest-period appears to be the only change made in the conditions of work, observations must be made over a long period until the results obtained satisfy statistical requirements. Variations in output and the rate of working are often profoundly influenced by fluctuations in the nature and quality of the raw material, atmospheric changes, and the like, and the output following the introduction of a rest-pause may be modified by these factors quite apart from the rest itself. Even the presence of an investigator will usually cause an increase in output for some days after his arrival, and in most industrial investigations the results of the first few days have to be discarded because of this fact. Further, when rests are first introduced, the workers often accelerate their rate of working immediately after the rest in order to make up for the time lost. As a result, the beneficial effects of the rest may be considerably reduced and cause a reduction in output. It is very difficult to obtain a clearly defined estimation of the effects of rests introduced under industrial conditions, but a scientific method of procedure, combined with suitable precautions, will usually ensure success.

3. General Summary.

The foregoing considerations show that when suitable rests are introduced in connection with laboratory or industrial work, the result is generally an improvement in the quality and quantity of output. In most cases the total output also is increased, in spite of the decrease in the actual time worked.

The effect of a rest is particularly beneficial in repetitive work of a monotonous character, and the influence on production is most marked in processes which are largely dependent on the

activities of the worker. Heavy muscular work, and operations involving a continuous standing or sitting posture, are also suitable cases for the introduction of rests. The speed of industrial operations is another factor which should be considered in relation to rests. Industrial conditions which require a working rate in excess of the natural rhythm of the body are conducive to fatigue, and, if unavoidable, their effects should certainly be alleviated by means of suitable rests.

There is evidence to show that in certain cases, the beneficial effects of a rest are not limited to the period of work following the pause, but are also noticeable before the rest occurs.

In general, however, the published work relating to rest-pauses in industry tends to raise more problems than it solves. In many cases there is a lack of unanimity in the results obtained, a feature which is largely due to the unscientific methods of procedure adopted. In industry, the introduction of pauses has been mostly empirical, and carried out without due regard to the nature and conditions of work. It is not surprising, therefore, that the effects have sometimes been unsatisfactory, and further developments in consequence discouraged Before rest-periods are introduced, a careful investigation of the existing conditions of work should be made, and a typical curve of output obtained. A consideration of such a curve will show whether a rest is necessary, and will indicate the most suitable position for the pause. Results obtained have shown that in certain cases, shorter but more frequent rests are preferable to fewer but longer rests, but further investigations are necessary in order to determine the most suitable number, duration, and distribution of rests for different types and conditions of work Investigations are also needed on the best methods of utilising rests in order that the most favourable results may be obtained.

Individuals vary in their susceptibility to the effects of rest and consequently the effects are more favourable in some cases than in others. Theoretically, the most suitable arrangement of rests will be different for different individuals, but in practice it is necessary to determine the conditions which will give the best average results. Further, an operative rests better when all the others are also resting, and her inclination to work is stimulated by the atmosphere of industry in the room.

The possibility of combining rests with team work has not been sufficiently explored. The few results which have been obtained show that such an arrangement is capable of reducing the cost of production, and at the same time enables the work to be done with less fatigue.

The results and remarks presented in this section of the report by no means exhaust the subject of rest-pauses, but they serve to indicate the number and variety of questions still awaiting solution in this aspect of industrial work.

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MEDICAL RESEARCH COUNCIL.

INDUSTRIAL
FATIGUE RESEARCH BOARD.

REPORT No. 43.

A Study of Telegraphists' Cramp.

By May Smith, M.A., Millais Culpin, M.D., F.R.C.S.,
and Eric Farmer, M.A.

LONDON:
Printed and Published by His Majesty's Stationery Office, and to be
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PREFACE.

In 1922 the Board were approached by the Union of Post Office Workers, who submitted various problems which in their opinion might appropriately be referred to the Board for investigation. On the application of the Board, the Postmaster General consented to give the necessary facilities for investigating means of minimising or preventing the liability to telegraphists' cramp (Morse and Baudot), and to appoint representatives on the Committee formed to direct the research.

The investigation, which has proved to be one of exceptional difficulty, has proceeded in several stages, and has dealt, not with those medical aspects of cramp already considered by a Departmental Committee in 1911, but with the question, arising from the work of that Committee, whether and how far there is a specific susceptibility to it amongst the persons engaged or about to be engaged in telegraphy. It has in short involved problems of individual selection, and in its general scheme has followed the course usual in research of this kind.

Attention was first devoted to two definitely distinct groups, the one consisting of telegraphists certified as suffering from cramp and the other of telegraphists apparently free from it. These groups were intensively studied, in order to find whether those suffering from cramp possessed in common any other characteristic not possessed in the same degree by those who had been exposed to an equal risk but had not contracted the disability. With this object selected psychological tests involving speed and accuracy of movement were applied individually, and a medical study of each subject was made, with special reference to the presence or absence of psycho-neurotic symptoms.

The results of this part of the investigation showed that in fact greater susceptibility to muscular fatigue (as measured by the ergograph), less ability to perform quick and accurate movements (as measured by the dotting machine), less complete control over the muscles when sending a message, and finally a greater prevalence of psycho-neurotic symptoms existed amongst the cramp subjects than amongst the normal subjects, but that the two groups were not completely differentiated by any of these tests, so that there was no assurance that liability to cramp could be detected with certainty in individual cases.

As the next step similar tests were applied to a random sample of learners in the school of telegraphy, with the object of opening the way to discovering whether those learners having characteristics shown to prevail amongst actual cramp subjects will in fact eventually contract it. Before a definite answer can be given to this question many years must elapse, but it may be of interest in the meantime to refer to the supplementary inquiry,

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the results of which are given in the Appendix to the report. In this a comparison is made between the gradings of the learners based on the tests and the examination and those based on the opinion of the individual's ability, formed by a superior officer. This comparison suggests that with the exclusion of those shown to be worst in the tests the percentage of those with the highest working efficiency would be considerably raised, in other words that the worst of those tested tend also to be the worst telegraphists, apart altogether from their liability to incur cramp.

Finally, a medical study of control groups of workers in other analogous occupations was made, in order to find out whether entrants into the telegraph service differ initially in respect of psycho-neurotic symptoms. The results were entirely negative, in that the incidence of such symptoms in the non-selected groups were approximately identical, the inference, so far as the smallness of numbers admit, being that the entrants into the Post Office are in no way different from entrants into allied occupations.

In an investigation like the present, conducted largely along untried lines, more definite results than those obtained could hardly be expected. In the opinion of the Board, however, they appear to suggest a field where further work is called for, and whilst at the present stage it will probably be felt that they are unsuitable as a basis for any administrative changes, they afford grounds for hoping that with the continuance of research on these lines knowledge will be gained as to the causes, not only of cramp but of other working disabilities, which will ultimately lead to results of great practical value.

The Board would express their indebtedness to the Members of the Committee appointed to direct the investigation, and to Professor M. Greenwood and his colleagues for their assistance in making the intricate comparison referred to in the Appendix.

June, 1927.

A STUDY OF TELEGRAPHISTS' CRAMP.

By May Smith, M.A., Millais Culpin, M.D., F.R.C.S., and Eric Farmer, M.A.

CONTENTS.

INTRODUCTION.

In 1911 a Report of the Departmental Committee on Telegraphists' Cramp was published by H.M. Stationery Office. The terms of reference of that Committee were "to enquire into the prevalence and causes of the disease known as telegraphists' cramp and to report what means may be adopted for its prevention."

By a process of exclusion the committee accepted the view that it was a disease of the central nervous system. Various objective factors, such as types of keys, length of service, hours of work, bad style, were reviewed and found not to be a necessary

antecedent. Even the physiological signs of cramp were shown to be indeterminate, as there might, or might not, be a visible spasm, and the disability in its objective manifestations could be specific to one letter, or be selective for certain muscular activities, or be associated with general muscular weakness. Details of six cases specially examined from the medical point of view were appended. In each case the organic condition was reported to be normal.

Scattered, however, throughout the report in connection with almost each suggested cause are references to "neurasthenic telegraphists," "cramp subjects," "nervous instability," "personal factors," "temperamental factors," "highly strung disposition," "nervous temperament," "nervous condition," "neurasthenic temperament." Here, from the context, it is clear that both the word "nervous" and its synonyms are being used with a different connotation from that in the phrase "nervous system," where the reference is to the actual organic nerves.

Since 1911 much work has been devoted to the problem of getting a clearer idea of that dimly recognised group of conditions indicated by such phrases as "nervous temperament" or "highly strung disposition." These are indicative of a type of person technically known as *psycho-neurotic*, who is suffering, or is liable to suffer, from pathological anxiety, obsessions, or hysteria. It is not known what organic conditions may be correlated with these states; they can only be studied as they are reflected in a subject's behaviour and his personal feelings.

There is in actual fact no gulf fixed between the normal person and the psycho-neurotic; most admittedly normal people have some neurotic symptoms, but not of such a character as to destroy their efficiency and personal happiness. Yet there is a practical difference between, for example, the reasonable anxiety of the normal person confronted with objective hazards and the unreasoning and incontrollable anxiety of the psycho-neurotic in the absence of objective cause, an anxiety which cannot be relieved by attempts to demonstrate its irrational character. The characteristic of a normal person as against the psycho-neurotic is his relative adaptability: the neurotic responds with the same pattern of behaviour and emotion to situations which objectively have nothing in common.

The chief objective fact in regard to cramp is that people engaged in telegraphy sometimes suddenly, sometimes gradually, become unable to control the movements required for telegraphic work. This would suggest some muscular difficulty due to the cumulative effect of the work, or to an initial weakness, or to the introduction of some new factor. Muscular trouble alone, however, is not sufficient to induce "cramp," as many telegraphists carry on in spite of it.*

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* Report of the Departmental Committee on Telegraphists' Cramp. Cd. 5968, p. 8.

The change of attitude of the medical profession to disabilities of this type is well exemplified by Kurt Mendel's article in the encyclopaedic *Handbuch der sozialen Hygiene,* edited by Gottstein, Scholssmann and Teleky, the second volume of which was published a few weeks ago.* Mendel defines " Occupational Neuroses " as " functional disturbances, i.e. such as are not the result of an organic lesion, which manifest themselves in the interplay of several muscles on the occasion of the exercise of a specific activity acquired by practice. They are, therefore, disturbances of co-ordination." In the section on pathogeny, Mendel states bluntly " since we are dealing with a 'neurosis,' that is with a purely functional and not organic illness, anatomical changes cannot be demonstrated, and so far never have been demonstrated." He specifies no less than 34 separate ' cramps ' of the upper extremity, including nine different ' cramps ' of musicians, a typist's ' cramp,' a shaving ' cramp ', a cigarette-maker's ' cramp,' a milker's ' cramp ' and, of course, telegraphist's ' cramp.' He also remarks that stammering bears the same relation to speech that writer's ' cramp ' bears to writing. He quotes, but without expressing approval, Oppenheim's opinion that miners' nystagmus is likewise an occupational neurosis.

PART I.

A. Outline of the Method of Investigation.

This investigation has pursued several lines of approach† :—

I. (*a*) The study of the achievement at tests involving speed and accuracy of movement of :—

(i) a group of telegraphists who were certified as suffering from " cramp " ;

(ii) a group of telegraphists who were carrying on efficiently.

At first sight this would seem to be useless, for it is already known that the one group can send telegrams, and that the other cannot ; but the power to " send " in telegraphy is probably the resultant of many complex factors and it seemed desirable to see to what extent, if at all, the groups differed with regard to other activities. These subjects were all accustomed to the Morse system.

(*b*) A personal enquiry which aimed at getting the point of view of the individual members of both groups as to the causes of cramp.

(*c*) A medical study of each subject with reference to those symptoms popularly called " nervous."

II. A study of a group of young telegraphic learners from the point of view of the presence or absence of " nervous " symptoms, and of ability at the tests.

III. A similar study of other groups of workers in allied occupations.

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* *Handbuch der sozialen Hygiene,* Vol. 2, pp. 530–540 (Berlin, 1926. Springer).

† Parts I (*a*) and (*b*) were carried out in collaboration with Mr. E. Farmer, the remainder in collaboration with Dr. Millais Culpin.

B. Description of the Tests and Results.

(*a*) *Test of Pressure Exerted*

The first test aimed at measuring the amount of pressure exerted when "sending" a telegram. For this purpose an apparatus was devised by the engineering department of the Post Office at the suggestion of one of us.* It consisted of an ordinary Morse key which worked on a drum containing fluid; the vibrations caused by the contact of the key were transmitted along a tube to another drum which registered the vibrations by means of a sphygmograph. The record, which was obtained on a smoked slip of paper, showed, unknown to the operator, the number of movements made by him, and the pressure exerted in making each movement as measured by the height of the contraction.

Each subject was asked to send a standard message from a printed card first at an ordinary rate such as he felt he could easily maintain for a considerable spell and afterwards at a rate which he himself could only do for a short time under emergencies. It was thought advisable to let each person determine his own pace as normal and quick rather than to demand conformity to an arbitrary standard Evidence that the subjects did actually send at two speeds is afforded by an examination of the records; the average number of contractions when sending at a normal rate was 26 as against 37·2 when sending quickly, thus showing that within a given time as measured by the length of the record a larger number of dots and dashes was sent.

Each record could be measured for :—

(*a*) The total number of contractions.

(*b*) The average magnitude of the contractions.

(*c*) The average deviation from the means of the contractions.

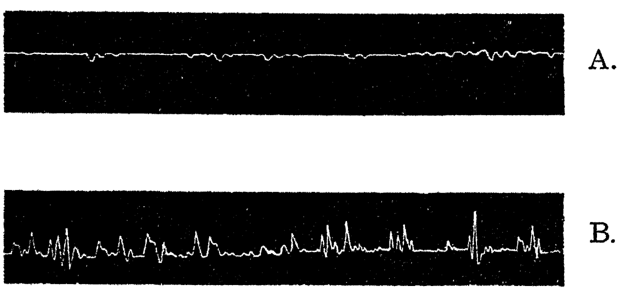


Fig. 1 —Showing the style of sending (*a*) a normal person (*b*) an advanced cramp case

* We are very much indebted to Colonel Booth for his valuable help in connection with this apparatus.

Fig. 1 illustrates the differences in the records obtained. It will be seen at a glance that the operator with cramp is exerting considerably more pressure than the normal person, and that there is much more irregularity. Such a person is expending more energy to achieve a given result: in the above example the telegram would probably have been unreadable to the " receiver " at the other end.

As there proved to be no statistically significant difference between the sexes for most of the tests, the results have been pooled except where the contrary is stated.

Results.

(1) The total number of contractions made by each person was calculated, but no significant difference between the average for each group was found, although there were considerable individual variations. As these variations were equally distributed between the two groups, they cannot be used as a means of differentiation.

(2) The magnitude of the contractions was measured in two ways:—

(*a*) The height on the records was measured on a scale and the average calculated.

(*b*) The records were classified into four groups according to the degree of pressure exerted. These groups were represented by the letters A, B, C, D; the A type is exerting the least pressure, the D type the greatest. (In the examples given in Fig. 1, A would be called A type, and B would be D type.)

TABLE I.—*Showing the Differences between the Two Groups in the Magnitude of the Contractions.*

Group.	Av. Ht. of Contractions in Units of ·05 in	(*b*) Percentage Distribution classified according to types of " sending."				
		Type A	Type B	Type C.	Type D.	Failed to do a record.
Non-Cramp ..	1·60 ±0·05	13·33	64·44	15·55	6·66	—
Cramp	2·31 ±0·12	4·76	45·24	26 19	19·04	4·76

The non-cramp group gives a larger percentage of A and B records and a lower percentage of C and D records than the cramp group, 49·99 per cent. of the cramp group being below the mean as compared with 22·21 per cent. of the non-cramp group. Expressed in units on the scale, the cramp group exert 44 per cent. more pressure than the others.

(3) By means of the coefficient of variability it is possible to compare two groups from the point of view of their divergence from the mean. Two groups might have the same mean and yet be very different practically, because in one case the individuals tended to cluster round about the mean and in the other to be scattered. In the case of the cramp group there is a greater variability, viz., $58 \pm 2 \cdot 2$ as against $48 \pm 1 \cdot 66$ for the non-cramp group.

In addition to sending a message at a normal rate each subject was asked to send quickly. Some of the cramp subjects were unable to do this at all. There are records from 39 of the normal subjects and 19 of the cramp subjects sending quickly, and these have been measured as described above. Obviously, the actual number of contractions has increased, because owing to the increased rate more "dots" and "dashes" were represented in the same space; the significant fact is that the average magnitude of each contraction in the non-cramp group has increased until it approximates to the cramp type, viz. $2 \cdot 136 \pm 0 \cdot 13$.

TABLE II.—*Showing the Effect of Increasing the Speed.*

Group.	Av Ht of Contractions.		Per cent. Diff.
	Ordinary Pace.	Speed Pace.	
Non-cramp	$1 \cdot 60 \pm \cdot 05$	$2 \cdot 136 \pm \cdot 13$	33
Cramp	$2 \cdot 31 \pm \cdot 12$	$2 \cdot 52 \pm \cdot 19$	9

Not every subject when speeded up increased the pressure, for, out of the 39 normal subjects 17 kept to their original class and all of the "A" type did, but 19, i.e. nearly 50 per cent., fell from B to C or to D; only three gave a better record. Thus the normal subjects when speeded up tended to exhibit the same kind of reaction as cramp subjects working at their own pace. The cramp group show the same tendency, and the magnitude of their contractions increased from $2 \cdot 309$ to $2 \cdot 52$.

(b) *The Ergograph Test.*

An ordinary Kräpelin Ergograph was used. This instrument is adapted for the study of relatively simple movements. The arm is placed on a fixed platform and fastened by means of cross-bars; the middle finger is free to execute upward and downward movements. The subjects were asked to move the finger as quickly as they could without rushing and to repeat the operation as often as they could, but no suggestion was made of the possibility of becoming fatigued and so of becoming unable to continue

the movement ; in fact, so surprised were many of the subjects when their fingers finally failed to act that they thought the weight had been increased or the machine had jammed. No metronome was used, so as not to introduce the factor of an imposed rhythm the effects of which, within the limits of this experiment, could not have been determined ; the weight was so adjusted that each subject could raise it with comparative ease at the beginning.

It happened, unfortunately, that the particular machine used proved unsuitable for women with very thin fingers and hence a number of them in both groups were unable to do the tests for reasons other than a specific disability ; the results obtained in this experiment have therefore been presented separately for men and women.

The records of these movements registered on smoked paper could be measured in three ways :—

(*a*) The total number of contractions made.
(*b*) The average magnitude of the contractions.
(*c*) The speed at which the subject worked measured by the number of contractions registered on the first 10 mm. of the paper ; those who paused between each contraction registering fewer contractions in the given distance than those whose reactions were quicker.

The test requires no intellectual effort.

TABLE III.—*Showing the Records of the Two Groups in the Ergograph Test.**

Group.		Total Number of Contractions.	Average Magnitude of Contractions in mm.	Number of Contractions in 10 mm.
Non-Cramp	Men	$34 \cdot 6 \pm 1 \cdot 96$	$38 \cdot 8 \pm 1 \cdot 1$	$7 \cdot 6 \pm 0 \cdot 46$
	Women	$20 \cdot 9 \pm 2 \cdot 55$	$30 \cdot 9 \pm 0 \cdot 1$	$6 \cdot 0 \pm 1 \cdot 07$
Cramp	Men	$24 \cdot 0 \pm 2 \cdot 1$	$29 \cdot 0 \pm 1 \cdot 26$	$5 \cdot 1 \pm 0 \cdot 55$
	Women	$13 \cdot 5 \pm 3 \cdot 07$	$32 \cdot 8 \pm 1 \cdot 76$	$5 \cdot 0 \pm 0 \cdot 60$
Difference	Men	$10 \cdot 6 \pm 2 \cdot 9$	$9 \cdot 8 \pm 1 \cdot 67$	$2 \cdot 5 \pm 0 \cdot 71$
	Women	$7 \cdot 4 \pm 3 \cdot 99$	$1 \cdot 9 \pm 1 \cdot 76$	$1 \cdot 0 \pm 1 \cdot 2$
Per cent. difference	Men	30·6	25	32·9
	Women	35·4	6	16·6

Table III shows that the cramp group was on the average less efficient than the non-cramp, but from the test one could not differentiate individuals.

* We are indebted to Mr. F. C. Bartlett, Director of the Cambridge Psychological Laboratory for the loan of the Ergograph.

(c) *The McDougall-Schuster Dotting Test.*

This test was devised by Dr. McDougall for the purpose of testing sustained voluntary attention and muscular control. The form used was the disc-dotting machine, a modification of the original, designed by Dr. Schuster. An irregular row of small circles 2 mm. in diameter with their centres marked is printed spirally in red on a paper disc 326 mm. in diameter. The spiral makes altogether two complete turns. The interval between successive circles, in the direction of the motion of the spiral is 5 mm , the lateral deviation is never more than 7 mm. The circles are thus clustered irregularly about the " true " line of the spiral. The paper disc is mounted on a plate fixed horizontally which rotates at a constant rate. A cover is supported above the plate in which a slot one inch wide is cut in such a position that as the disc rotates, every point of the spiral row of circles presents itself to view through the slot. The subject rests his wrist on the cover and aims at the circles as they appear through the slot at one edge and are carried out of sight at the other. He starts at the inner end of the spiral and makes his way outwards

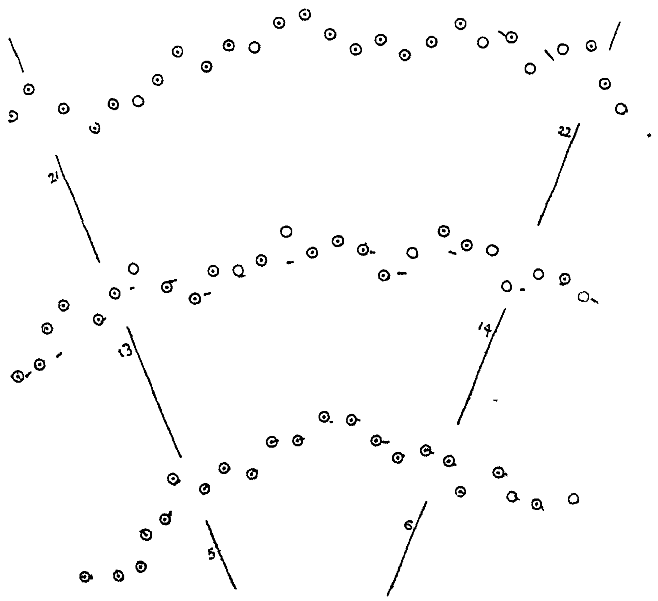


FIG. 2.—PART OF A BAD RECORD (DOTTING TEST).

over it as its whole length presents itself point by point through the slot. At the inner end of the spiral an angular movement of 45° brings six circles out from under the edge of the slot; at the outer end of the spiral 24 circles. Thus the subject has to work at a gradually increasing rate. If the subject touches the circle with the pen, it is counted as correct; he is not expected to hit

the centre. Comparison of Figs. 2 and 3 shows that in Fig. 2 only two circles are attempted in the outer portion, whereas in Fig. 3 all are attempted, though some are failures.

The number of circles correctly hit with a stylograph pen gives the score. Extra uncontrolled " dots " count as errors.

The average number of correct hits made by the non-cramp group was $160 \pm 4 \cdot 5$; by the cramp group $101 \pm 6 \cdot 2$. As with the other test there was considerable over-lapping in the middle ranges.

A subject might produce a poor record, (*a*) when, although he recognised mentally where he has to aim, he could not control the movements of his hand ; (*b*) when, although he had muscular control for what he could recognise, he could not keep his attention fixed or was slow to adapt ; (*c*) when through over-anxiety to do well he tried to go back to correct errors, or when he " rushed at " the dots.

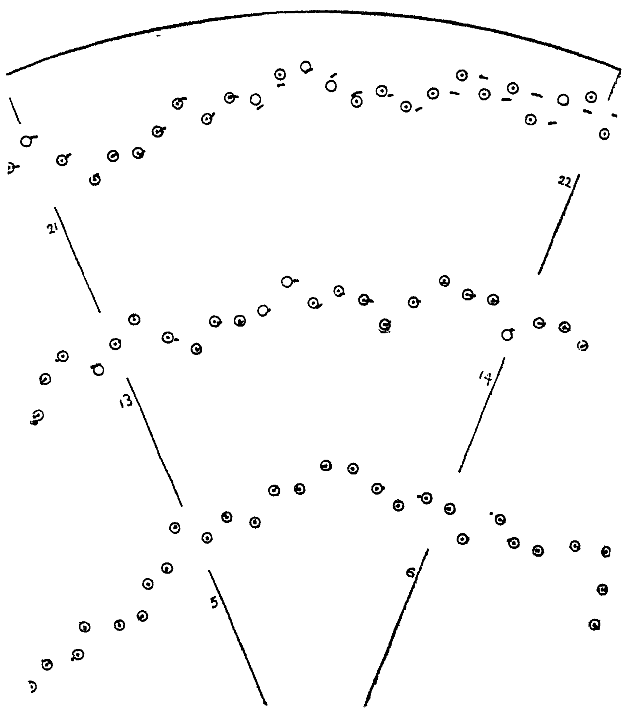


FIG. 3.—PART OF A GOOD RECORD (DOTTING TEST).

(d) *Comparison of Tests.*

In order to facilitate comparison the subjects were graded for each test and for all the tests combined into four classes, those in the first group being the best and those in the fourth the weakest.

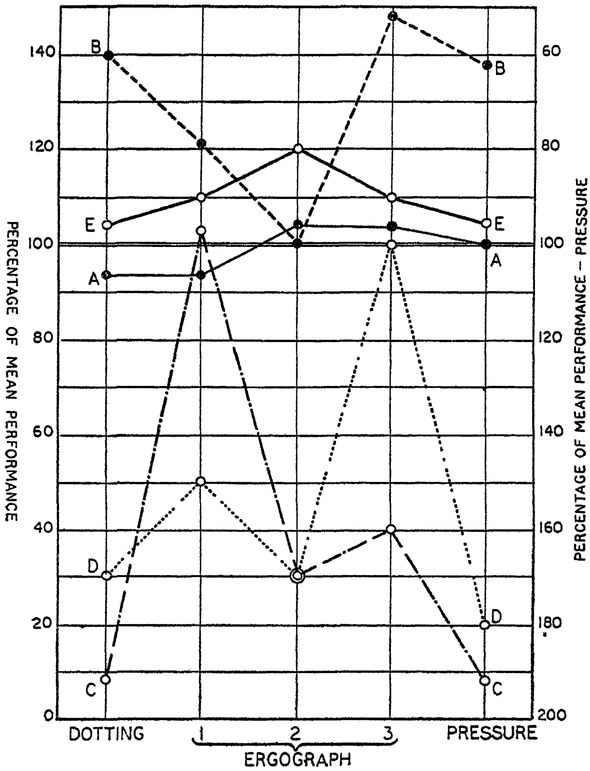
TABLE IV.—*Percentage Distribution of Subjects for each Test.*

Group.	Pressure Test.				Dotting.				Ergograph.												Tests Combined			
									Total No of Contractions.				No. of Contractions in 10 mm.				Average Height of Contractions							
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Non-cramp	13·0	58 7	19·6	8·6	19·6	39·2	32·6	8·7	24·0	39·5	13·1	24·0	18 4	42 1	31·6	7 9	29·1	63·2	5·3	2·6	41·3	30·4	23·7	4·3
Cramp	4·9	46·3	27·0	22·0	4·9	14·7	39·2	41 5	—	33·3	27·3	39·4	12·1	18·2	36 3	33 3	27·3	30 3	30·3	12·1	17·0	19·5	26·8	36·5

Table IV shows that in each test there are fewer A and B records and more C and D records among the cramp group than among the non-cramp group, but nevertheless among the cramp subjects there are some who are as efficient as those of the other group, so that from the tests there would be no reason to suspect these individuals as suffering from cramp.

C. Examples of Individual Cases.

A few examples of individual cases will illustrate the general differences between cramp subjects and non-cramp subjects and also the type of cramp subject with no specific muscular disability. For the purpose of comparison the average for each test was taken to be 100 and the individual variations corrected accordingly. Fig. 4 represents these graphically. A and B are records of subjects who have no cramp symptoms. They found their work tiring towards the end of the day, but were all right after a rest.



A-A. Normal subject showing an average record.
B-B. Normal subject showing a superior record
C-C Advanced cramp case.
D-D. Advanced cramp case.
E-E. Cramp case with no muscular disability.

Fig. 4.—General differences between cramp and non-cramp subjects.

A conforms very closely to the average, while B shows superiority. C and D are cases of cramp. One of these C is just above the average for the total number of contractions made in the ergograph test, but he is below the average for everything else. D just reaches the average for the height of his ergograph contractions, but is below for everything else. E is an example of a case of cramp which apart from telegraphy has no muscular disability known to himself or discoverable by these tests.

The scale for the pressure records is inverted as the better the record the fewer the units of pressure ; in the other tests the higher the record the better it is.

D. Personal Opinions of Operators.

In addition to doing the tests the subjects were asked for their own opinions concerning the causes of cramp. These statements have been analysed and tabulated as follows :—

1. *Length of service*

Some thought it was related to length of service, but the range of age and service before the onset of the disability is great ; in the majority of the cases here studied the disability did not manifest itself until after a considerable period of work, e.g., about 20 years, but in some cases only about 2 years had been worked.* There are many people who have served still longer who yet remain free, even though with advancing age their muscles are less agile. Clearly length of service is not the determining factor.

2. *The Mechanism of the key, style of sending and conditions of work.*

With regard to keys both groups criticise keys which are too stiff or not well balanced, although there are those who assert that the key makes no difference to them personally. It is however maintained by the majority that some keys put too great a strain on the muscles of the arms.

Another cause is summed up in the phrase " bad style," by which seems to be implied a too cramped position of the fingers,

* The average age of the various groups is 43 for the men non-cramps and 49 for the men cramps as against 24 for the women non-cramps and 35 for the women cramps. It would have been better for the purpose of the experiment if the ages of the two groups had been more nearly equal, but it was impossible to arrange otherwise. Although reliable evidence as to the actual date of the onset of cramp in the case of those suffering from it could not be obtained, yet there appeared to be a notable difference between the men and women in this respect. The women on the whole seemed to break down before the men. The difference between the two may be due to the natural desire of the men not to prejudice their chance of promotion by being officially recognised as cramp subjects, while for various reasons this factor may not operate to such an extent with the women.

wrist and arm, and as a resultant a cramped position of the whole body, which leads to a lack of "fluidity" in the movement. Instead of a steady rhythm being maintained each movement or group of movements is jerky so that physiologically there is entailed a sequence of partially arrested movements.

Aiming at too great a speed before proficiency is really attained is assigned by many as an important cause. Early ambition to become an excellent telegraphist has tempted some to over-strain and the mischief seems to be done in the first few years in the "galleries". Whether it is really the type that aims at speed (either to seek promotion or because he must rush at* things) that breaks down or whether the speed does play a part in inducing cramp could not be determined.

Too long hours at manipulative work is a reason often given, and in this connection some maintain that the special arrangement of the 10-hour and 6-hour day alternating is not good; it has, however, for quite other than physiological reasons, many supporters. The alternation of "receiving" and "sending" cannot be looked upon as physiologically an adequate rest, although it is realised as a mental change and as such is beneficial.

A constant feeling of being under supervision appears to some to add to the other strains and in not a few cases unsympathetic supervisors or superintendents (themselves probably worried) have added to the difficulties already present.†

The noise in the gallery and the strain of both sending and receiving are important to some.

3. *Temperament.*

A "nervy" temperament is given a prior place in the list of causes by the majority of the subjects, both among the "cramp" sufferers and the others. Exactly what is meant by "nervy" in this connection it is difficult to determine, but to a request for specific instances the answers usually indicated a temperament characterised by the undue strength of fear. Even among the normal group there are some who describe themselves as "nervy," but they are fewer in number than among the cramp group.

Suggestions made by the Subjects.

Suggestions for the amelioration of cramp naturally are related by those questioned to the assigned causes. There is no unanimity on the subject of keys, some preferring one type, some another and some professing indifference, but there are some who would like

* The type of person who must "rush at" his work is not peculiar to telegraphy, and in many occupations the attitude is likely to cause difficulties.

† It makes no difference to certain types of persons whether those in authority actually are or are not unsympathetic; their reactions are quite frequently to their own idea of a person, and this may bear no relation to the actual character of the person.

keys to be adjustable to the individual. Much greater agreement exists on the subject of speed, which many maintain ought to receive no encouragement until the operator has been several years out of the training school. Before full maturity is reached the extra strain involved in "flying" is almost certain to have bad results later, when, owing either to the cumulative effect of the work, or to the personal anxieties attendant upon adult responsibility extra strain is put upon the operator.

Some suggest that as the years of service increase the hours of manipulative work should decrease for the average telegraphist and also that in the ordinary working day, week or month, manipulative and non-manipulative work should alternate. "Receiving" which entails constant writing and so employs almost the same muscles as those used in "sending" can never be a satisfactory alternative to "sending."

With regard to the more personal peculiarities there is a general consensus of opinion that unless there is excellent reason to the contrary people of a "nervy" disposition ought not to be appointed. The discovery of the particular form of "nerviness" likely to cause failure in a telegraphist entails many difficulties. The personal characteristics required by a good telegraphist according to those interviewed are, an ability to remain calm when rushed, a non-worrying disposition and a capacity for disregarding the work when not actually engaged in it.

E. Types of Disability.

The problem of telegraphists cramp would be simpler if each sufferer had the same symptoms; instead of this there is a confusing diversity varying from person to person. The following are some of the types met with :—

(1) There are those suffering from a general disability to use the arm after many years of sending; not only is the use of the telegraphic key or a pencil interfered with, but also most other actions which demand the use of the arm. The holding of a cup, or of a needle for sewing or knitting is difficult or impossible; a glass if taken up may be dropped; even the handle of a spade cannot be grasped. This disability may or may not be accompanied by pain, which may be localised in the wrist or may be general.

(2) There are those who can neither send nor write but who can use the arm for other occupations, e.g., they can play the piano, use a spade and are quite efficient if the larger muscles are brought into action. This group comprises very many individual variants from ability to use the arm for anything except telegraphic work, through various grades of inability, to total disability as described in the previous section.

(3) Others again are all right, having no pain, and no muscular disability except for the sending of a particular letter or group of letters. Particular combinations of dots and dashes prove stumbling blocks. Some have difficulty in letters involving a sequence of dots, particularly at the end of a word; others find that having got the key down they cannot get it up again quickly enough for the formation of dots, in other words the key seems "sticky."*

If one particular letter were always the cause of the trouble the remedy would be easier but there are few letters of the alphabet that have not been given as difficulties. While certain sequences are likely to be more difficult if there is any loss of control, some of them have probably a purely individual significance. The complexity of this aspect of the case is made much greater owing to the fact that there are at least three elements involved in telegraphic work which may have personal meaning and lead to difficulty.

(i) The actual form of the letter.
(ii) Some association connected with the letter.
(iii) The significance of the particular combination of dots and dashes.

Sometimes the onset is quite sudden; the telegraphist has a feeling, which comes upon him like "a bolt from the blue" as if he could not send a particular letter: the letter then seems to stand out in relief from all the others and is anticipated with dread and greeted with panic. His state is reflected in a style of "sending" which the telegraphist at the other end of the wire has difficulty in "reading." He protests, so that to the initial painful mental state is added the objective effects of inefficient work. The sufferer feels innocent and may react with antagonism to those around him, or recognise his inefficiency, but still feel he is powerless to alter it. Even if this state were the invariable sequence a remedy would be relatively simple, viz., to accept such initial difficulties and take the telegraphist off. There are, however, many subjects who have admitted that they have had occasional difficulty with certain words and sequences, but that it has passed away; the mechanism of this passing away is obscure, but it probably involves improvement in general health, and absence of the fear of cramp, and temperamental stability. The fear of cramp is very real to many telegraphists and probably plays no small part in determining the attack, which, without this, might be temporary muscular tiredness, relieved by rest.

F. General Conditions of Telegraphic Work.

Telegraphic work involves, over and above the particular degree of intelligence required—

(1) Speed and accuracy under variable stress.

* A similar disability sometimes affects typists, but owing to the form of the machine it is less likely to have serious consequences at an early stage.

(ii) The constant presence of a potential critic at the other end of the wire.
(iii) Generally working with, and in the presence of, other people.
(iv) A rapid muscular action involving delicate movements which, being under conscious control, can be easily disturbed by mental anxiety.
(v) A rigid objective standard of attainment.
(vi) Finality of attainment, i.e. an error made cannot be recalled without being known to someone other than the agent.

Not all people are temperamentally fitted for successful work under these conditions. The intellectual qualities would seem to be but a relatively small part of the total equipment required. In our experience, no allied occupation appears to make quite such exacting demands. The fine movements employed can reflect, much more quickly and certainly, emotional changes which would fail to disturb grosser movements, e g an anxiety, real or psychoneurotic, could easily come between the sufferer and his telegraphy, whereas the same mental state in a typist might show itself in errors of which she alone need know, and might fail to be reflected at all objectively in the work of a machinist Hence the importance not only of muscular efficiency but of emotional poise for the successful telegraphist.

G. Results of a Medical Study of Emotional Differences.

The next stage of the investigation was to examine the two groups to see if any difference in emotional make-up or development could be discovered.

It is now comparatively easy to test for, and assess a subject's general intelligence, but there are no reliable objective methods of testing for temperament and character. Reliance has therefore to be placed on the observation and interpretation of a doctor experienced in such work. The method adopted was somewhat as follows :—

(i) General observation of the subject, such as we are all accustomed to make.
(ii) Guided by knowledge of many subjects, the external behaviour and appearance were linked up to the mental state of which they were probably the expression.
(iii) By questions framed so as to bring up different situations in life, it was possible to study the subject more fully and accurately, and thereby verify, disprove or modify the earlier impression.

It often happened that when once started the subject would give a very detailed personal account of himself, in which case the investigator would not interfere with questions.

To study a subject merely as the doer of a particular piece of work is of little value ; the work to the worker is part of a whole, made up of his numerous reactions to situations, real and ideal, over and above the work. Sometimes it is the phantasy life that is of more importance to the individual than the apparent real life It is clearly impossible to obtain a thorough knowledge of any one, but it has proved possible to get the point of view of a subject with sufficient clearness to yield an insight into the relation of the work he does to his general attitude to life. Merely general statements concerning loss of some mental function, such as memory or attention, complaints about nervousness etc., are of little use. The general must be particularised and examples must be given of specific cases where the impairment of function has revealed itself. People will frequently complain of loss of memory: when, however, particular examples are required it is found that the so-called general loss is decidedly specific, quite as specific as is a telegraphist's inability to send one particular letter while having control over the movements for every other letter. These variations are valuable for diagnostic purposes.

Investigation of over 300 subjects working under different conditions has shown us very clearly that there are people in whom fear, in one or other of its protean forms, plays a disproportionate and uncontrollable part: whether this is due to its innate strength, or to some early environmental influence, or to both, cannot be here determined. The fear however will not remain merely a mental state, but will show itself openly or covertly in the various situations of life. Some examples of individual reactions to ordinary relationships will perhaps serve to make this clear :—

(i) *Individual variations of reaction to authorities.* The attitude of people to their authorities, immediate and remote, varies to an extraordinary degree. The emotional range includes interested curiosity, indifference, mild apprehensiveness and fear that can be reproduced with almost hallucinatory vividness. A certain respect for authority is reasonable, but the person who is terrified even at the idea of interviewing anyone in authority, and responds by some or all of the instinctive fear responses, linked up with an intellectual realisation of impending blame, though knowing there is no objective cause, is not likely to withstand the stresses inherent in ordinary life.*

(ii) *Individual variations of attitude to observers.* To be somewhat uneasy when observed at one's work is common, and varies from slight discomfort, through control achieved by added effort, to, in some people,

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* It is assumed that the authorities concerned are not really overbearing ; there are conditions when fear of authorities would be reasonable . with these we are not here concerned.

complete loss of control. A subject with this fear in an extreme form might carry on easily in work that could be done alone, or if the work were of a purely mechanical nature, his mental disquietude could not be reflected in it. In telegraphy, the very nature of the work involves the possibility of frequently stimulating this fear. Among cramp subjects it proved to be a very common sympton, not related to the cramp as a result of the cramp, but forming an integral part of the subjects' mental make-up.

In the closely related disorder of writer's cramp the sufferer sometimes experiences difficulty only when observed and some stammerers can easily read aloud when alone.

(iii) *Relation to oneself.* A capacity to judge oneself in relation to others also varies within a wide range. There is at the one extreme the person who can never be sure he is right; should he be challenged on the most obvious thing the challenge will immediately cause doubts to arise; he will say he is never sure of himself, that he is always wondering if he is right and even the assurance of a competent outsider will fail to carry effective conviction. At the other extremity is the person who is equally irrationally sure he is right, who can brook no criticism. Both attitudes are indicative of a mental stress which may, added to other stresses, play a part in determining breakdown, and no ordinary environment could give complete satisfaction. The normal person can see himself in perspective and challenge, accept or rebut criticism reasonably.

(iv) *Relation to one's fellow workers.* Two extreme types are well known to everyone, viz., (*a*) the person who is "shut in," who finds it difficult to get into touch with others and, failing to adapt, retires still further within himself, (*b*) the person who readily gets into touch with others, who can quickly and almost unwittingly realise other people's points of view and emotional variations and adapt to them. Between these extremes lies an infinite range of variations. Those, however, who more nearly approximate to the first type are less likely to adjust happily to conditions where other people have to be considered than are the second. Those who habitually play no games, take no part in any social life, make no friends, dislike strangers and prefer to be alone as a rule, show characteristic symptoms. It is necessary to distinguish adolescent shyness, which might make a young boy or girl appear unsociable while merely inexperienced, from the characteristics described above. The distinction is not difficult to make in practice.

(v) *Attitude to one's work and conditions of that work.* Sometimes subjects, instead of realising their mental attitudes as subjective experiences, objectify them and experience the personal state as a quality of their work or of the conditions of the work. Hence noise, light, stuffiness, types of keys and machines assume a disproportionate importance.* If only the particular feature which appears so wrong to the particular person could be altered, all would be well; the psycho-neurotic nature of the characteristic is disclosed when the alteration is made and the mental state is then reflected in some other impediment.

In others there is an irrational inability to consider a piece of work finished, they can never be sure as to the accuracy or completion of any task. They take abundant pains while doing it, finish it with meticulous accuracy and then begin to have doubts about it. As long as is possible, they keep the work under their own control, if it has gone they try to recall it and when away from their work are liable to see the mistake they have not committed as a persistent visual image. The severity of this symptom varies from an occasional attack, which at one time or another may affect anyone, to a total incapacity to dismiss a thing as finished.

(vi) *Attitude to more general conditions.* Other fears in disproportionate strength, such as fear of the dark, of traffic, of being alone, of people etc., need not in themselves affect work, but their presence points to an unstable temperament and it is rare to find any one of these standing alone.

Expression of these characteristics in telegraphy.

Some of the above mental attitudes are primarily expressed in general reactions to life; some get direct expression in telegraphy. The telegraphist with the *sentiment d'incomplétude*, as Janet calls it, cannot resist the impulse to recall the message he has sent as long as that is possible, and when it is impossible, he will worry about it.

There are those, well known to the teachers in the training school, who want an unnecessary number of repetitions; some who "rush at" dots when under observation or when they happen to think they are being observed; some who find adaptation to people at the other end of the wire, who happen to be somewhat different from themselves, perhaps in speed, a source of irritation; some who for no consciously known reason worry as to whether

* This aspect was clearly marked in a typewriting investigation into the effect of rubber caps for keys It is true that there may be objective cause for complaint: with that we are not here concerned. Other reports have dealt with that aspect.

they have sent three dots or four dots. With some, the mental state is reflected in anything connected with telegraphy, while with others it is more liable to be expressed on one instrument than on another, when fatigued than when fresh, when working against time than when working easily, when consciously worried than when unworried. Where the normal person would either adjust or accept conditions, or frankly face them as impossible, the psycho-neurotic may respond with some symptoms of a more or less disabling type. He is not consciously aware of what is happening in most cases ; in some cases he is aware of something in himself over which he has no control and will respond with fear, sullen acquiescence, or strenuous efforts to control, according to his type, but never with an easy mastery. Obviously the strain is great

As illustrative types the following examples are given. No one subject would be represented by either A.B. or Y.Z. : the individual cases vary considerably but the types do give a general idea of extremes.

> A.B. finds his work interesting, and looks forward to getting on at it—goes in for sports or hobbies—is sociable, enjoys being with his fellows—if shy at first with strangers becomes less so with experience—respects authority but is not overwhelmed by it—can be observed without undue emotion, has no particular fear of the dark, noises, etc.—doesn't worry about his work when it is finished—sleeps well—can go at an easy pace in telegraphy—can hold his own opinions with and against his fellows—can realise himself in relation to others reasonably. An approximation to this we should call normal, particularly if combined with a healthy physique and cheerful expression.
>
> Y.Z. thinks the work interesting, but is doubtful whether he is making progress—is never sure of himself—worries when he has done a thing as to whether it is right—is conscious of being watched in trains, buses or restaurants—goes back to make sure he has done what he thinks he has—likes to check his work many times—dislikes all games and social activities—doesn't feel at ease with people—irritated and frightened by authorities—speculates on the possibility of the floor giving way or the building falling down—upset by noises—always wants to rush at dots. Such a type we should class as psycho-neurotic and under the conditions of telegraphic work we should anticipate the development of cramp.* An ultimate breakdown will be modified by the natural vitality of the person, but given two people of the same vitality and conditions of work A.B. will carry on efficiently where Y.Z. will break down.

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* In other occupations where there is no specifically recognised occupational disease, people of this type would tend to have a " nervous breakdown," or if physically very strong to have abnormal work curves or be " difficult."

In the case of some subjects it is possible that a mere question is inadequate as a stimulus to call forth the response appropriate to the situation expressed, and an indifferent answer might be forthcoming which may or may not be representative. The person who camouflages all emotion under the guise of intellectual indifference can hardly be detected in a short interview, but a suspicion of the camouflage is sometimes given, and in one or two cases these subjects were revealed by their behaviour when doing the tests. With the majority there was little doubt that as far as they had conscious awareness of their attitude they were expressing themselves honestly.

Some, however, showed a peculiar mental attitude characterised by an undue stress upon the absence of nervousness. This attitude resembles " la belle indifférence de l'hystérique " as described by Charcot, and is in contrast to the attitude of a normal person

Results.

Of the 41 cramp cases examined, 31 (=75·6 per cent.) showed symptoms which would lead, quite apart from the cramp, to the diagnosis of a minor mental disturbance (a psycho-neurosis) characterised by anxiety, obsessions or hysteria.* The degree of severity varied, but in 26 of the cases the symptoms were of a serious nature. One subject was suffering from an organic lesion. 9 (= 22 per cent.) cases showed no symptoms, as far as we could discover, other than a subjective experience of cramp, and in 6 of these there was no disability as measured by the tests. Of the 46 non-cramp subjects 30 (i.e. 65 per cent.) were, with some reservations in the case of the women†, classed as not suffering from psycho-neurotic symptoms, 15 (32·5 per cent.), had psycho-neurotic symptoms in varying degrees. One subject was a case of mild recurrent melancholia.

In Table IV (p 10) the two groups are compared from the point of view of efficiency at certain tests and it is shown that on the whole the cramp group is less efficient than the other, but that there are some subjects who, although cramp cases, are quite efficient at these tests. The number of these is 15 (36·5 per cent.); 9 of these, however, showed symptoms which would lead to a diagnosis of a psycho-neurotic disposition. There are 6 who, apart from subjective symptoms of cramp, would, within the limits of a research investigation, be classed as normal.

* The particular form of disability characteristic of the majority of those with anxiety or hysteria was pain, either localised in the arm or wrist, or diffused through the whole body: if they had difficulty with letters or figures, usually fairly large groups of letters were affected. The obsessional group on the contrary were characterised by difficulty with one particular letter and rarely had pain

This statement can only be taken as representing this group of subjects: we have no evidence to show how general it may be, the obsessional type of person being relatively few in any group.

† The numbers are too small for any valid sex distinction to be made, but the women of the group called non-cramp, had a lower level of mental equilibrium than the men.

The dotting test, which differentiates the two groups more rigidly than any one of the others, had 8 (i e. 19·5 per cent.) of the cramp group who were above the average; of these 4 had psycho-neurotic symptoms, one had an organic lesion, and 3 had no symptoms other than cramp. Of the 17 in group D for this test 16 had some psycho-neurotic symptoms, 11 of them of a serious nature.

We have thus two sets of symptoms. On the one hand, there is impairment of efficiency, which may be quite general affecting most activities, or quite specific and limited to the one act of telegraphy; on the other hand, a set of mental conditions, such as undue anxiety, hysterical symptoms or obsessions. These two sets may be related as follows:—

(i) It may be that although both occur in one person yet there is no causal relationship between them.

(ii) The physical symptoms may be the cause of the mental symptoms, and some cases suggest this view.

(iii) The mental symptoms may be the cause of the muscular inefficiency and some cases suggest this.

(iv) The mental symptoms and the muscular inefficiency may both be the expression of some unknown factor.

In the cases reported above we find muscular inefficiency with and without psycho-neurotic symptoms; we find muscular efficiency with and without psycho-neurotic symptoms. The commonest picture is the muscular inefficiency allied with psycho-neurotic symptoms and the suggestion is offered that where such symptoms are present, there is every possibility of cramp developing in the event of any strain.

It is not claimed that these particular tests are superior to all others; any test requiring for its successful execution accurate and highly controlled movement would probably be useful. These seemed to be sufficiently interesting to challenge attention and stimulate desire to succeed.

That the tests do measure something different is shown by the absence of correlation between them. The only significant correlations are between the right and left hands in the ergograph test, and different measures of the same test.*

A subject who showed himself good at all the tests can have little wrong with his muscular co-ordination; while a subject weak at all of them is likely to have difficulty with telegraphy. In the 1911 report it is suggested that in selecting candidates, those with stiff wrists, clumsy hands and inability to write easily should be noted. Such characteristics would certainly prove a hindrance to the successful performance of these tests and in particular of the " dotting," so that the tests would thus furnish an objective criterion.

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* With these exceptions the range is $\cdot 099 \pm \cdot 18$ to $\cdot 48 \pm \cdot 07$.

H. Types of "Sending."

A supplementary investigation was undertaken to see if any light could be thrown on the style of laboured sending characteristic of a number of the cramp subjects by a study of the pressure exerted by young learners. This investigation was conducted in the school of telegraphy where girls and boys desirous of becoming telegraphists are trained. There were two sets of learners in the school at the time, a group of girls who had been learning telegraphy for about 10 weeks and a group of boys and girls who had been learning for over 30 weeks. Twenty-six girls who had been in the school about 10 weeks, 21 girls and 19 boys who had been in over 30 weeks were available for this experiment

As they were beginners they were asked to send "dots" and "dashes" instead of a standard message. They were all familiar with the actual technique of sending. About ten records were obtained from each subject, on successive days and as nearly as possible at the same time of day. This enabled a study to be made of the degree of fixity in the style of sending for each subject and also of the change, if any, in type according to their experience.

The records were classified and graded with the letters A, B, C, D, as already explained. Care was always taken to see that each subject actually made contact, and special attention was paid to this factor in the case of those in the A group who sent so lightly and easily that their record was practically a straight line.

It sometimes happened that the "dots" were made with little or no pressure, but that the "dashes" (although actually only a "dot" three times as long) were produced with great pressure. In marking, it was the dashes in these cases that determined the classification. It only happened once (and that not with a "learner,") that more pressure was exerted with a "dot" than with a "dash."

TABLE V.—*Showing the Percentage Distribution.*

Type.	26 Girl Juniors	21 Girl Seniors.	19 Boy Seniors.
	per cent.	per cent.	per cent.
A	37·0	47·5	44·3
B	22·2	44·5	30·7
C	15·2	4·9	9·1
D	25·5	2·9	15·9

It will be seen that there is a difference between the juniors and both the girl and boy seniors, with regard to all types. Fewer "A" and "B" records, and more "C" and "D" records appear among the juniors than among the seniors.

The larger percentage of "D" records among the boy seniors compared with the girl seniors was due to the presence of several boys with unusually bad styles of sending; the "A" group

among the boys is almost as high as among the girls, showing that a light pressure is not a peculiarity of the girls. It is significant that the three senior girls who exert the greatest pressure are described in the school report as showing a tendency " to rush dots."

It has been shown above that many cramp subjects exert too much pressure when sending and that some normal subjects when speeded up also tend to increase the pressure. This being so it is very probable that as learners they did the same. Now it is undesirable in any learning process to fix a bad habit, even temporarily. it may eventually be abandoned, but unfortunately it is not lost. There is a tendency to return under certain conditions to a type of activity once learnt, even though it has been overcome by practice. Such a return is technically known as " regression." " Some action which has been acquired in perfection and has become automatic may be disturbed by failure of control and is consequently carried out in an inferior manner."* The conditions favourable to this tendency are those involving loss of control. One cannot argue that all learners with a heavy style of sending will become cramp subjects; it is rather that, if the heavy style has ever been fixed, then, should circumstances arise in later life which interfere with control, there will be a likelihood of easy regression to this style with its attendant drawbacks.

Summary of Part I.

Examination of a group of subjects certified as suffering from cramp and of a group of normal telegraphists has shown :—

(1) That the cramp group is weaker from the point of view of efficiency at the tests and also that the larger proportion of its members have symptoms of a psycho-neurotic nature, apart from cramp.

(2) That there are some cramp subjects who have no symptoms, other than a disability affecting " sending " in telegraphy.

(3) That the type of " sending " characteristic of the cramp subjects is too heavy and that this may, on the analogy of other automatic actions, represent a regression to an earlier style.

PART II.

Examination of Learners.

The next stage of this research was to test learners in the school of telegraphy to see if any of them were akin to those of the " cramp " group, and if so to determine the frequency of the type. For this purpose 100 young learners, boys and girls, were tested as the previous groups had been :—

(*a*) with reference to the presence or absence of pyscho-neurotic symptoms, and

(*b*) by the application of the tests previously used modified to suit the different ages of the subjects.

* Head, Henry. The Medical Problems of Flying, p. 253. M.R C. Report, No. 53.

(1) *Presence or absence of psycho-neurotic symptoms.*

In this series a slight change in the classification was made, the advisability of which had been revealed by experience. The earlier investigation, being mainly concerned with the diagnosis of adults, many already suffering from "cramp," had been limited to differentiating those with severe symptoms from the others. In this and the following studies a three-fold classification was adopted, viz., those with no symptoms, those with severe symptoms, and an intermediate group approximating at the extremes both to the pyscho-neurotic and to the normal, whose liability to breakdown will in all probability be determined by their environmental conditions of life and work.*

Results.

Of the 100 young learners who were interviewed 54 could be described as showing no predisposition to psycho-neurotic breakdown, i.e. they were of the type likely to be able to adjust to the ordinary conditions of life efficiently and happily; 27 could be described as slightly unstable, i.e. they form a border line group approximating at the extremes both to the psycho-neurotic and to the normal; 19 showed definite psycho-neurotic tendencies, 6 of them in such an acute form as to admit, even at this age, of classification in one of the recognised groups of psycho-neurosis.

(2) *Application of Tests.*

(A) The degree of pressure exerted in "sending" was measured but instead of a standard message the subjects were asked to send "dots" and "dashes" in their usual style. They were graded as described above into four classes. For the purpose of comparison the records of a similar test done on another group of learners are included in Table VI It will be seen that the distributions are very similar.

TABLE VI.—*Showing the Percentage Distribution of Two Groups of Learners.*

	A.	B.	C.	D.	Total
	Per cent	Per cent.	Per cent	Per cent.	Per cent.
100 learners	36	27	17	20	100
Another set of learners . ..	37	22·2	15·2	25·5	99·9

* Some people do actually have an easier time in life than others, judged objectively; and hence while having a temperament which is likely to involve breakdown, yet may always succeed in being in an environment suitable for them. Given a slightly unstable person, who happens to have domestic troubles, economic anxiety, and a rush of work at the same time, he will break down; the same person might carry on in the absence of any one of these conditions.

Those called A and B were sending fairly easily and with very little pressure; C and D put too much pressure on the key and were irregular. Most of the C group will with experience become much easier; the D group was composed of those who were putting considerable pressure on the key. The drawback to the presence of this habit, even if eventually given up, is that there is a tendency to revert to it under the stress either of speed or emotional excitement. It involves an unnecessary expenditure of energy to achieve a given effect.

(B) *The McDougall-Schuster Dotting Test described above.* No modification either in method or classification was made.

(C) *The Graphic Pursuit-Meter.* This test was not used in the first investigation.

The apparatus devised by Dr. Schuster embodies the idea of Miles' "Pursuit-Meter," but it is more simple in construction and employs different mechanical principles.

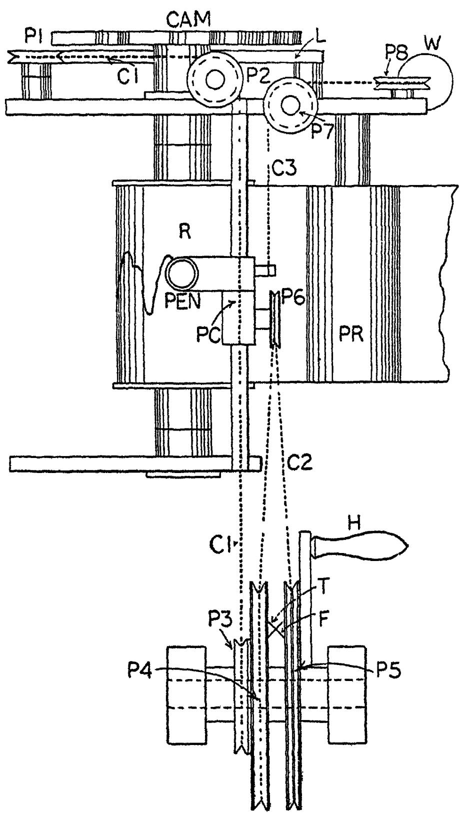

FIG. 5.

* Miles, W. R., *J. Exper. Psychol.*, 1921, vol. 4, p. 77.

The task set for the subject is as follows: The triangular white pointer (T. fig. 5) attached to the pulley wheel, P4, is given a backwards and forwards movement, which may be regular or irregular, according to the shape of the cam referred to later. The subject is required to keep the pointer, F, attached to the pulley wheel, P5, exactly opposite T by movements of the handle, H. The movement is imparted to T by means of the cam (CAM) which rotates at a constant speed and raises and depresses the lever, L. A cord, C1, is attached to the lever, L, at one end, passes round the pulleys, P1 and P2, and is attached at its other end to a point on the periphery of the pulley, P3. Thus the upward and downward movement of the lever L are translated unto oscillating movement of pulley P3 and consequently of pulley P4, which is attached rigidly to P3 A coiled spring round the hub of P3 keeps the cord C1 always in tension.

The accuracy with which the subject follows the movements of T is recorded in the following way: A cord, C2, attached at one end to the periphery of P4, passes over its upper side, then round the pulley P6, and back along the under side of P5 to the periphery of which its other end is attached. The pulley P6 is carried on a pen carriage, PC, which is free to slide backwards and forwards along a square guide. The pen carriage is pulled in one direction by the cord C2 and in the other direction by the cord C3, which passes round pulleys, P7 and P8, and is kept in tension by the weight W. The pen writes on a strip of paper passing from the paper roll, PR, over the top of the flanged roller, R, and then back under the paper roll. The paper is held in frictional contact with R, by means of another roller (not shown) carried on a hinged bracket and forced against R by means of strong spring R is mounted on the same spindle as the cam and is rotated with it by means of suitable clockwork (not shown). The rotation of R causes the paper to pass under the pen at a constant speed.

If the handle, H, is kept stationary, the oscillation of the pulley, P4, by winding and unwinding the cord, C2, causes the pen carriage to move backwards and forwards along its guide and the pen to trace a curve on the paper, which reproduces in a modified form the contour of the cam. If, however, the subject is performing his task perfectly by keeping F exactly opposite to T, just as much cord is always wound on to P5 as is unwound from P4, or vice versa, and in consequence the pen carriage does not move, and the pen traces a straight line. The nearness with which the curve traced approaches a straight line is thus the measure of the success of the subject. A special scale ruled on plate glass is used to estimate this.*

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* We are indebted to Dr. Schuster not only for making the machine but for describing it.

Fig. 6 shows two of the records obtained, one good the other poor.

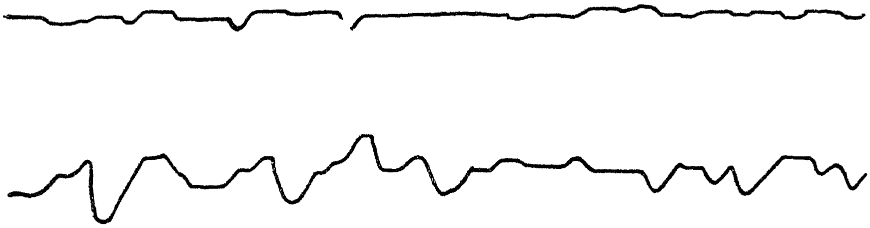

FIG. 6 —SPECIMEN RECORDS OF PURSUIT METER TEST.

(D). *The Ergograph.*—The standard type used before was replaced by a portable one designed by Dr. Schuster, which had the advantage of being much simpler, smaller and less impressive.

All that the subject had to do was to flex and extend the third finger as quickly as possible for one minute, and a record was obtained on paper of each contraction. From the record it was possible to compute the number of contractions made in the time and the height of each contraction. In order to compare with the previous investigation the number of contractions made by each person in the first 10m.m. of the printed record was counted. The difference in the machine prevents a comparison between these records and those obtained from the other instrument with regard to the total number of contractions.

Results.

As with the other set of subjects, there was an absence of correlation between the various motor tests. The range is from $+\cdot 17$ to $-\cdot 03$. except for the right and left hand of the Ergograph ($\cdot 69 \pm \cdot 04$). The general results are shown in Table VII.

TABLE VII.—*Showing the Means and the Co-efficient of Variability.*

Test.	50 Girls.		50 Boys.	
	Mean.	V.	Mean.	V.
Dotting	174 ± 2·9	26·4	160 ± 2·7	25·5
Pursuit Meter	31 ± 1·2	41	25 ± 1·2	50·4
ERGOGRAPH. Average Total Number of Contractions Right	108 ± 2·31	22·4	121 ± 2·3	20·2
Do. Left	100 ± 2·03	21·3	117 ± 1·94	17·3
Average Number of Contractions in 10 m.m. Right	6 ± 0·14	25·3	7 ± 0·10	17·7
Do. Left	6 ± 0·11	18·3	7 ± 0·12	17·3
Average Height of Contractions Right	41 ± 0·68	17·5	38 ± 0·55	15·1
Do. Left	44 ± 0·66	15·7	39 ± 0·50	13·5

The subjects were graded for each test into four groups as in the earlier investigation. (Table VIII).

TABLE VIII.—*Percentage Distribution of Subjects for each Test and the Tests Combined.*

	Pressure in "Sending"				Dotting.				Pursuit Meter.				Total No of Contractions				No of Contractions in 10 mm				Average height of Contractions				Combined Tests.			
No.	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
100	36	24	18	22	9	40	38	13	18	40	35	7	9	32	42	17	5	31	36	28	7	38	39	16	18	39	34	9

TABLE IX.—*The Distribution according to the Tests Separately and Combined, and the Presence or Absence of Psycho-neurotic Symptoms.*

Psycho-neurotic Symptoms		Pressure. in "Sending."				Dotting				Pursuit Meter				Ergograph. Total No of Contractions.				Ergograph. No of Contractions in 10 mm.				Ergograph. Average Height of Contractions				Tests Combined.			
		A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
None (54)	Number	22	9	10	13	5	19	26	4	11	17	22	4	5	15	23	11	3	12	21	18	6	19	21	8	*10	*20	19	5
	Per cent.	41	17	18	24	9	35	48	7	20	32	41	7	9	28	43	20	6	22	39	33	11	35	39	15	18	37	35	9
Slight (27)	Number	8	7	6	6	4	14	5	4	6	14	7	—	3	7	16	1	1	11	11	4	1	13	7	6	5	14	8	—
	Per cent.	30	26	22	22	15	52	18	15	22	52	26	—	11	26	59	4	4	40	40	15	4	48	26	22	18	52	30	—
Severe (19)	Number	6	8	2	3	0	7	7	5	1	9	6	3	1	10	3	5	1	8	4	6	0	6	11	2	3	5	*7	*4
	Per cent	32	42	10	16	—	37	37	26	5	47	32	16	5	53	16	26	5	42	21	32	—	32	58	10	16	26	37	21

The subjects having been classified according to the presence or absence of psycho-neurotic symptoms and according to their efficiency at the tests, the following groups appear :—

I. Those showing no psycho-neurotic symptoms and who are:—
(*a*) good or fairly good at the tests.
(*b*) poor at the tests.

II. Those with slight psycho-neurotic symptoms and who are:—
(*a*) good at the tests
(*b*) poor at the tests.

III. Those with definite psycho-neurotic symptoms and who are :—
(*a*) good at the tests.
(*b*) poor at the tests.

Taking the results of the tests combined (Table IX), the figures marked with asterisks show that there are 30 who have no psycho-neurotic symptoms and who are above the average at the tests, and 11 who have severe symptoms and are below the average at the tests.

It will be seen that there is no direct relation so far as these numbers are concerned, between efficiency at the tests and psycho-neurotic symptoms, i.e., from the tests alone we cannot infer the presence or absence of such symptoms. But from a consideration of the " cramp " cases in the previous section, where it was shown that the commonest type had psycho-neurotic symptoms, it is unlikely that subjects with such symptoms will pursue a telegraphic career for many years without breakdown : those poor at the tests are likely to have difficulty with the movements required and to get some disability eventually not only on account of the natural weakness but because its presence makes it an easy medium for the expression of emotional disturbance. The combination of poor co-ordination and psycho-neurotic symptoms would indicate every possibility of cramp developing.

TABLE X.—*Showing the Average and the Variability of the Subjects*

Psycho-neurotic Symptoms	Dotting		Pursuit Meter		Total No of Contractions		No of Contractions in 10 mm		Average height of Contractions.	
	Mean	V	Mean.	V	Mean	V	Mean	V	Mean	V.
None .	171±3·7	24·4	29±1·1	42·8	113±2 4	23·4	6·3±0·1	25·0	41±0·62	17·0
Slight .	170±6·1	27·9	24±1·46	46·8	119±2·52	16·5	6·6±0·19	21·4	43±1·01	18·5
Severe.	145±7·2	30·6	31±1·4	50·0	115±4·4	23·6	6·5±0·19	18·3	39±0·71	11·5

These tests quite apart from their use for grading subjects with regard to their efficiency at tasks demanding muscular co-ordination also illustrate the way in which some activities allow of the expression of psycho-neurotic symptoms whereas others do not. It will be seen from Table X that although the

differences between the means and the coefficients of variability for the various tests are not statistically significant, yet those of the dotting test are nearer to being so than the others, and the group forming the connection between the two extremes lies also between both with regard to the average and coefficient of variability. Taking these tests as examples of output a "nervy" subject might carry on efficiently at work of a type that does not easily reflect variations in personal well-being, whereas such a subject would find his output affected with his personal changes when the work was of a more refined type.*

The "dotting" test is of the latter type Designed by Dr. McDougall as a test of voluntary attention, probably the most unstable mental state, it serves to reflect indirectly any condition which is perturbing a subject. Certain anxiety types, the over-scrupulous, those with a fear of observation, tend to make mistakes or to break down at an early stage. People of this type but with naturally quick powers of adaptation sometimes betray themselves in the way they do the test, even though their actual production falls within the normal range, e g., when on the second spiral they try to rectify an error on the first, or to go back on themselves, to "dot" wildly when they find the speed increasing, to grip the pen stiffly. The average number of "dots" correctly marked by these subjects is low; on the other hand a severe obsessional case might, and as a matter of experience can, do extremely well at the test, when it may be assumed that there was nothing in the apparatus which could "touch up" his obsession.† Hence the greater variability of the psycho-neurotic group (30·6 as against 24·4) and also a lower average.

This test has advantages over any other test of its nature for research work, carried out under factory or office conditions. It is done quickly; it is interesting and not trivial; it offers a challenge, so that subjects try their best to do it, and the apparatus is simple and not too impressive. For these reasons it was the only test used with the control group of 100 clerical workers.

Summary of Part II.

From an examination of 100 learners it has been shown :—

(*a*) That it is possible at the age of 16 to differentiate the psycho-neurotic type from the more normal and those with weak muscular co-ordination from the others.

(*b*) That 11 per cent approximate to the type characteristic of the majority of those with "cramp" viz, psycho-neurotic symptoms and weak muscular co-ordination

(*c*) That tests alone are not sufficient to differentiate those with, from those without, symptoms.

(*d*) That 19 per cent. have severe symptoms.

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* In typewriting we have found a connection in some subjects between psycho-neurotic tendencies, and output curves characterised by a wide range of variability. (*Ind. Fat. Res Bd 5th Ann Rep*).

† Since writing this we have met with several examples of persons of the obsessional type who do this test excellently.

PART III.

SIMILAR EXAMINATION OF OTHER GROUPS OF CLERICAL WORKERS IN THE CIVIL SERVICE.

The next stage in this investigation was to examine other groups, working under somewhat similar conditions as to security of tenure, status, etc., to see if the incidence of psycho-neurotic symptoms and muscular efficiency were the same. It would be desirable to know the incidence in the general population and the variation according to age, but that is a problem for future work In this connection we only had two control groups, a group of 100 clerical workers and a group of 34 typists. Groups 1, 2 and 3 have already been discussed.

TABLE XI.—*The Incidence of Psycho-neurotic Symptoms in Different Groups.*

Psycho-neurotic Symptoms	Percentage Incidence				
	1. Non-Cramp Telegraphists.	2. " Cramp " Group.	3 Learners	4 Typists.	5. Clerical Workers.
None	65	22	54	55·9	54
Slight	—	—	27	26·5	20
Severe	32·5	75·6	19	17·6	26
(Exceptions) ..	1 = organic lesion.	1 = psychotic.			
Number ..	46	41	100	34	100

Table XI shows that the percentage of subjects without psycho-neurotic symptoms does not vary much in groups 3, 4 and 5 Group 1 was already a selected group, nor had we when examining groups 1 and 2 started to differentiate the slightly psycho-neurotic , had we done so it is certain that some in the 65 per cent. would have been in this group. The people with definite psycho-neurotic symptoms are a much more clearly defined set.

Group 5 was also tested with the dotting machine as described above Table XII gives the dotting records of all those who were tested, arranged according to their mental type. It illustrates the tendency to a lower average and a greater variability in the psycho-neurotic group which culminates in the exaggerated " cramp " type. In isolation no one difference is statistically significant (excepting that between the groups of normals and the " cramp " group), but the consistent small differences all in the same direction are of importance.

TABLE XII.—*Dotting Records and Mental Type.*

Psycho-neurotic Symptoms	100 Learners		100 Clerical Workers		46 Non-Cramp Subjects and 41 Cramp Subjects	
	Mean	V	Mean	V	Mean	V
None .	171±3 7	24 4±1 64	183 6±3 68	21 9±1 49	176±5 31	23 7
Slight .	170±6 1	27 9±2 71	183 0±5 8	21 1±2·34	—	—
Severe .. .	145±7 2	30 6±3 8	170 6±5 5	24 7±2 39	148±5 8	22 6
(Cramp subjects)	—	—	—	—	101±6 8	64±6 48

One could not argue that the test of itself would enable one to detect psycho-neurotic individuals, but it has an average value, and it is pertinent to note that of the 13 subjects who come under " D " for their group (see Table IX) only 4 are classed as having no symptoms, 5 are slightly psycho-neurotic and 4 have severe symptoms. On the other hand, of the 9 who fall under " A," 5 are classed as having no symptoms, and 4 are slightly psycho-neurotic ; no one shows severe symptoms.

There is a type of person naturally slow of movement who might do very badly at such a test as the dotting merely because of his slowness ; one can generally detect such a person by other signs, and it is improbable that he would be successful at telegraphy

As the tests and the medical examination were conducted by the writers separately and in ignorance of one another's findings, the consistency of variation is some objective evidence of the reliability of the subjective standard.

PART IV.

GENERAL SUMMARY AND CONCLUSION.

The investigation here reported can only be regarded as of the nature of a first experiment. The problem of " cramp " is important not only in itself, but also as an example of an industrial disability which may fundamentally be typical of others manifested in different ways. Previous research had shown that there was no one condition of the work, and no specific organic state that could be regarded as the invariable antecedent of " cramp." The general lines of this research were as follows :—

I. An attempt to determine by selected tests the differences, if any, between those with and those without cramp. Two groups were so tested.

The results showed that while many of the " cramp " group now had varying degrees of muscular weakness, others could not be differentiated by such tests from normal people.

II. A study of telegraphic work showed that it made demands of a more exacting nature than other allied occupations: demands which affected the emotional rather than the intellectual life.

III. The subjects were therefore examined from the point of view of the presence or absence of symptoms which are technically known as psycho-neurotic. These may or may not be caused by, or associated with, organic changes; our knowledge is inadequate to determine the relationship. In practice they show themselves in emotional reactions of a relatively unstable, uncontrollable, and unadapted type: in popular speech the sufferers are called "highly strung" or "nervous."

It was found that the "cramp" group consisted of a majority of subjects with such symptoms in a severe form. The commonest picture of a "cramp" subject was the presence of severe psycho-neurotic symptoms allied to muscular weakness; there were several individual deviations from this.

IV. The next problem was to see if this nervous type could be detected at the age of 16 For this purpose 100 young learners were examined.

It proved possible to differentiate them into those with psycho-neurotic symptoms and those of more stable development. They were also tested for muscular ability. From the results it was possible to find out those who approximated to the "cramp" type.

V. Lastly, other groups of clerical workers, not engaged in telegraphy, were similarly tested to see if in such groups the relative proportion of psycho-neurotic and normal people differed from or agreed with that found in telegraphists.

It appeared that the proportion of subjects with symptoms indicating liability to breakdown was roughly about 20 per cent. The evidence would suggest that people of this type are more likely to break down at telegraphy than those of more normal development In occupations other than telegraphy there is some evidence that these subjects tend to have a "nervous breakdown" or suffer from symptoms suggestive of a nervous origin, but their symptoms could not find direct expression in their work.*

VI. In so far as these findings are correct, the conclusion would be that people who show psycho-neurotic symptoms or poor muscular co-ordination, and particularly if in combination, should not be advised to take up telegraphy. There is no reason why they should not be efficient at some other occupation, especially if placed where their abilities find adequate scope, and where their particular emotional make-up does not receive constant stimulation in the work. This aspect of the problem belongs to the field of vocational guidance, and points to the necessity for considering the temperament of the child and the emotional stress of the work, as well as his intelligence and motor aptitude.

There seems also to be some danger in encouraging, actively or tacitly, too great speed. Telegraphists when speeded tend to increase the pressure exerted, which means that not only is more

* Further research in this direction is now in progress.

work done in a given time, but that each movement is done with more exertion. Not all people will be affected, but many will. More serious, though, to certain persons is the feeling of strain induced; this mental state might lead to breakdown in any of those approximating to Y.Z. described on page 20.

The problem of those already suffering from cramp is more difficult. Cramp appears to bear the same relation to other symptoms in the same patient as do such recognised psycho-neurotic manifestations as stammers, tremors and functional paralyses. It occurs in conjunction with anxiety and obsessional states; it occurs in a form obviously hysterical; and it occurs as an isolated symptom in perfectly healthy subjects who present no other abnormal manifestations. In a large proportion of cases it would appear that treatment should be directed to the general condition, of which cramp is only the most conspicuous symptom. It is probable that attention given to the emotional state of the patient when cramp first appears might in some cases suggest a means of preventing the development of the trouble.

It is pertinent to enquire why telegraphy should have a specific "cramp" when other occupations of an allied nature have not.* Although the evidence is limited, yet we have shown that the proportion of normals to psycho-neurotics is not very different in other groups. We would suggest that the exacting nature of the work, the inevitable rigidity of the conditions, the isolation of this one symptom, with its disabling effects, have all operated to concentrate attention into this channel. The type likely to get cramp may have a nervous breakdown in other occupations, but it is also probable that many who break down in telegraphy might carry on more or less efficiently under conditions more amenable to individual requirements. In England telegraphy is a permanent occupation, which to some is one of its attractions; in America there is more mobility of labour and the disease is hardly recognised. As against the advantage of permanence one may have to put the disadvantage of relative immobility. The relation between these two factors is a problem for future work. Should such general conditions become characteristic of any other allied occupation, we should expect a similar result, viz., some form of disability affecting that part of the body which is most used or essential for the particular process, and the people likely to be affected to be that group called in this report the psycho-neurotic. Expressed more generally, a person emotionally unstable working in an environment either actually, or conceived of by him as, inflexible will have just that interaction of conditions necessary for "cramp" or some similarly determined disorder

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In conclusion, we would like to express our thanks to those who in the interests of scientific research allowed themselves to be subjects, and also to those in authority who allowed the daily sequence of work to be interrupted by outsiders

* There are individual cases of cramp in many occupations (see page 3) but they do not constitute a group large enough to require special recognition.

APPENDIX.

A STATISTICAL NOTE ON CERTAIN OF THE DATA CONTAINED IN THE PRECEDING REPORT.

by Professor M. GREENWOOD, F.R.C P.

(Chairman of the Statistical Committee of the Medical Research Council)

The report by Dr. Culpin, Mr. Farmer and Miss Smith is principally concerned with a description of methods of physiological and psychological assessment and a comparison of the results of applying these methods to persons clinically diagnosed to be suffering from, or to have suffered from, Telegraphists' Cramp and to a control series So far as the results needed statistical treatment, that has been given by the authors themselves.

In the second and third parts of the report, the results of applying these methods of examination to entrants into the Telegraph service and to other employed persons are recorded and, here also, a suitable statistical control has been employed.

There remained, however, one avenue unexplored. The learners who were the subject of investigation in Part II of the report had, at the time it was drafted, an average service of many months, and it was possible both to examine their sickness records and to obtain judgments of their efficiency.

The position was that, in respect of rather more than a hundred young men and women, it was possible to classify each, (1) on the basis of the tests applied while the person was still a learner, (2) on the basis of the opinion as to the individual officer's ability formed by a superior officer, (3) on the basis of recorded sickness

It is, of course, obvious that no analysis of this information could throw *direct* light upon the main problem, because the service experience was far too short for there to be the least expectation that, in any of the subjects, symptoms of cramp would emerge. It is also clear, on statistical grounds, that unless very large differences between the averages of different subgroups were found no conclusive answer to *any* question could be expected. It seemed, however, advisable to scrutinise the data for the following reason The judgment formed as to the practical ability of officers by their superiors is not infallible, but, in all efficient services, it is weighty. If any method of examination applied *at entrance* were capable of anticipating or predicting that judgment, it would, quite apart from any value it might have in other ways, be of use in increasing the efficiency of the service, for it would direct attention to the learners who were, or were not, likely to become useful officers. It would, of course, be puerile to suppose that *any* tests could completely anticipate judgments based on subsequent experience, and, as already mentioned, the present data are too scanty to *demonstrate* any correspondence, or correlation, unless it were far closer than it would be reasonable to expect Yet, as any such discovery would give the methods of investigation value in a field quite different from that of the primary investigation, it seemed worth while devoting some attention to the subject. For these reasons, the necessary data (compiled in a manner fully safeguarding individual secrecy) were submitted to me and very minutely analysed by my colleagues of the staff of the Statistical Committee.

I do not propose, in this note, to enter upon the details of the analysis, but only to refer to one or two points of obvious interest. It will be sufficient to say of the rest of the work that, although nothing emerged contradictory of any of the authors' conclusions, as stated in Parts II and III of the report, the variability of the constants computed was too great to

admit of the deduction of any unambiguous statistical conclusions. We were in the normal position of statisticians, the numbers were too small for us to build upon and larger samples were, from the nature of the case, unobtainable

The points of interest to which I will refer were two. The first is that, so far as males are concerned, even this, statistically speaking, small experience is large enough to make it improbable that Dr. Culpin's and Miss Smith's assessments are *statistically* independent. In other words, since the assessments were *personally* independent—i e neither investigator was influenced by a knowledge of the other's results—these apparently very different tests are, to some extent, gauging the same quality or group of qualities in the individual psychological make-up The second and practically more interesting point is this Suppose we rejected from the group of learners those persons who failed to do well under either Dr. Culpin's or Miss Smith's tests, should we, from the point of view of the administrator's classification, improve the average quality ?

In the tables that follow are shown both the absolute numbers and the percentage distributions of the males and females as classified after practical experience.* Take, then, first the males and consider what percentage distribution we should obtain if we excluded all who were adjudged by Dr. Culpin to belong to his worst class (2 +) or by Miss Smith to her worst class (d).

TABLE A.—*Percentage Composition of the Population (Post Office Classification) under different conditions —Males*

Condition.	Post Office Classification †					
	A	B	C	D	A & B	C & D
As it now is	19 2 (10)	17 3 (9)	28 8 (15)	34 6 (18)	36 5 (19)	63 5 (33)
As it would be if all who were either 2 + or d were rejected	25 0 ± 2·5 (9)	19 4 ± 2·4 (7)	27·8 ± 2 9 (10)	27 8 ± 3 0 (10)	44 4 ± 3 0 (16)	55·6 ± 3·0 (20)
As it would be if all who were either 2 + or 1 or c or d were rejected	30 8 ± 6 4 (4)	23 1 ± 6 2 (3)	15 4 ± 7·4 (2)	30 8 ± 7 8 (4)	53 8 ± 7 9 (7)	46·2 ± 7 9 (6)

† The top figure in each case gives the percentage and the figure in brackets the actual numbers

TABLE B.—*Percentage of the present numbers in each class that would be rejected under different conditions —Males.*

Condition	Post Office Classification					
	A	B	C	D	A & B	C & D
If all who were either 2 + or d were rejected	10 0 ± 8 9	22 2 ± 9 5	33 3 ± 6 8	44 4 ± 6 0	15 8 ± 5 7	39 4 ± 3 3
If all who were either 2 + or 1 or c or d were rejected	60 0 ± 8 4	66 7 ± 8 9	86 7 ± 6 4	77 8 ± 5 6	63 2 ± 5 4	81 8 ± 3 1

* In this note the various classifications from best to worst are distinguished as follows :—

Post Office.	*Miss Smith.*	*Dr. Culpin.*
A, B, C, D.	a, b, c, d.	0, 1, 2+

The answer is that the proportion in the best class, the A's, would be increased from 19·2 per cent. to 25 per cent., and in the two better classes, the A's and B's, from 36·5 to 44·4 per cent. It would thus appear that the elimination of those unfavourably judged by Dr. Culpin and Miss Smith would very considerably improve the quality, as determined by administrative experience, of the staff. Indeed, if we go further and eliminate all save Dr. Culpin's "normals" and Miss Smith's a's and b's, we increase the percentage of "administrative" A's and B's to 53·8 per cent, and of A's to 30·8 per cent.

Statistically, this result is not so impressive as it seems If we have a bag of n balls p of which are white and take out of the bag m balls, on the average, $\frac{m\,p}{n}$ of the m will be white, but if m is small relatively to n we may, by mere luck, have wide deviations from $\frac{m\,p}{n}$. The usual measure of these fluctuations, the "probable error" of the expected number is

$$\cdot 67449 \sqrt{\frac{p\,(n-p)}{n} \times \frac{n-m}{n-1}}$$

(if we wish to express our results in percentage form, we simply multiply $\frac{m\,p}{n}$ and its "probable error" by $\frac{100}{m}$), and unless the actually observed numbers differ from the expected numbers by say three or more times this "probable error," we certainly cannot feel any great confidence that the result is more likely to be due to a "real" relation between the qualities tested by Dr. Culpin and Miss Smith and those judged by the administrators than to "chance." Applying this criterion to the instances quoted, we find that the improvement from 19·2 to 25 per cent., i e. 5·8 per cent., is subject to a "probable error" of 2·5. The improvement from 36·5 per cent to 44·4 per cent, 7·9, is subject to a "probable error" of 3·0 and that from 36·5 per cent to 53·8 per cent, 17·3, to a "probable error" of 7·9. Each deviation is between two and three times the size of the "probable error" (the three calculations are not independent, so that the three results are not independently confirmatory one of another), and might, therefore, not very infrequently arise as mere freaks of sampling.

As will be seen from Tables C and D, application of the same method to the female examinees leads to very similar results The selection leads to an improvement, but the advantage, in proportion to the "probable error" of the determination, is less As, however, these two samples, viz., those of males and females, are statistically independent, the fact that there is a qualitative agreement between them is a confirmation of the suggestion

TABLE C.—*Percentage Composition of the Population (Post Office Classification) under different conditions.—Females.*

Condition	Post Office Classification					
	A Very Good	B Good	C Very Fair	D Fair	A & B	C. & D.
As it now is .	19 6 (11)	19 6 (11)	26 8 (15)	33 9 (19)	39 3 (22)	60·7 (34)
As it would be if all who were either 2 + or d were rejected	21 3 ± 1·6 (10)	19 1 ± 1 6 (9)	27 7 ± 1 8 (13)	31 9 ± 1 9 (15)	40 4 ± 1 9 (19)	59 6 ± 1 9 (28)
As it would be if all who were either 2 + or 1 or c or d were rejected	25 0 ± 4 8 (5)	25 0 ± 4·8 (5)	20 0 ± 2·7 (4)	30 0 ± 5 8 (6)	50 0 ± 6 0 (10)	50·0 ± 6 0 (10)

TABLE D.—*Percentage of the present numbers in each class that would be rejected under different conditions —Females*

Condition.	Post Office Classification					
	A	B	C	D.	A & B	C & D.
If all who were either 2 + or d were rejected	9·1 ± 6 8	18 2 ± 6·8	13 3 ± 5 5	21 1 ± 4 7	13 6 ± 4 2	17 6 ± 2 7
If all who were either 2 + or 1, or c or d were rejected	54 5 ± 8 8	54 5 ± 8 8	73 3 ± 3 6	68 4 ± 6 1	54 5 ± 5 4	70·6 ± 3 5

each conveys. But the odds against chance being responsible for the increased proportion of administrative A's and B's reached in *both* samples by keeping only Dr. Culpin's normals and Miss Smith's a's and b's are not substantial It is also to be noted that this method of selection would exclude no less than 54·5 per cent. of female A's and B's and 63·2 per cent. of male A's and B's, that is more than half those reported to be very good or good. It would reject 81·8 per cent of male C's and D's and 70·6 per cent. of female C's and D's. Such a selection would be very drastic.

The conclusion we may, I think, draw is that, quite apart from its bearing upon the main problem, viz., that of the aetiology of telegraphists' cramp, the system of tests devised by Dr Culpin and Miss Smith does explore qualities, the presence or absence of which have some relation to service efficiency. There is reason to believe that further work on these lines might be of practical value in the problem of vocational selection for entrants as it arises in the Telegraph services.

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Report No. 44.

MEDICAL RESEARCH COUNCIL.

INDUSTRIAL
FATIGUE RESEARCH BOARD.

The Physique of Women in Industry.

A CONTRIBUTION TOWARDS THE DETERMINATION OF THE OPTIMUM LOAD.

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REPORT No. 44.

The Physique of Women in Industry.

A CONTRIBUTION TOWARDS THE DETERMINATION OF THE OPTIMUM LOAD

BY

E. P. CATHCART, F.R.S.,
and E. M. BEDALE, M.A., C. BLAIR, M.B., K. MACLEOD, M.B.,
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PREFACE.

The subject of weight-lifting and carrying by women is one that has already engaged the attention of the Board, who initiated an investigation under the supervision of Professor E P. Cathcart, F.R.S., and published the results in 1925.* This investigation, which dealt primarily with the relative advantages of different methods of weight-carrying, showed that when judged by the physiological cost (the oxygen consumed per minute), these methods, irrespective of the actual weight carried, could be arranged roughly in order of merit, depending mainly on the degree of displacement of the body necessary to bring the centre of gravity over the feet, but also in some degree on other factors, such as the amounts of chest-fixation, muscular tension, local strain, and interference with the normal gait.

Suggestive as these results were, however, they did not throw—and were indeed not designed to throw—light on the equally important question, the maximum weight of load that can be carried without injury or discomfort, beyond showing that with some modes of carriage, loads above a certain weight caused an abrupt and large increase in the cost, owing to some factor involving strain or discomfort.

A request that the investigation should be continued so as to include this second point has since been made to the Medical Research Council by the Home Office. It was pointed out that the lifting or carrying of weights by women and girls has long been regarded as a matter requiring regulation, but that while it has been possible to insert provisions on the subject in codes of regulations made for dangerous or unhealthy industries, there has hitherto been no general or specific provision in the Factory Acts in regard to it. A proposal to rectify this omission appeared in the Factories (No. 2) Bill, 1926, Clause 47, which ran as follows :—

> "(1) A woman or young person shall not lift, carry or move any load so heavy as to be likely to cause injury to such woman or young person.
>
> (2) The Secretary of State may make special Orders prescribing the maximum weight of the load which may be lifted, carried or moved by women or young persons of any age ; and any such Orders may relate to women or young persons generally or to women and young persons employed in any class or description of factories, or when engaged in any process."

In these circumstances, the Home Office requested that the actual load that can be lifted or carried by women and young workers under industrial conditions without injury or discomfort should be the subject of scientific investigation, pointing out that, in the event of the new powers contemplated in the Bill being approved by Parliament, the results of such an inquiry would afford them valuable guidance.

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* BEDALE, E. M. (1925) : "The Effects of Posture and Rest in Muscular Work." *Report No. 35.*

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The Board were again fortunate in obtaining the consent of Professor Cathcart to direct the investigation. It was obvious from the beginning that if trustworthy conclusions were to be drawn, the problem would have to be attacked from several different aspects, and the data collected over a very wide field Accordingly, three simultaneous lines of inquiry were designed In the first place, an extensive survey was made in order to collect anthropometric data of about 4,000 women engaged in different occupations and of suitable controls. The following measurements were taken for each woman :—

(*a*) Weight.
(*b*) Height.
(*c*) Length of arm
(*d*) Distance of finger-tips from ground (standing).
(*e*) Three physical strength tests, two of them involving the use of muscles ordinarily employed in industrial practice and one of them the use of muscles rarely employed.

The results of this part of the investigation are of special value in showing the variations in these attributes amongst women, and in indicating the extent to which the stronger women tend to gravitate towards the more strenuous occupations. Further, they throw some light on the way in which the exercise of strength depends on mental alertness as well as a muscular capacity. In the determination of the physiologically economic load, it was found that the best rough physical indication of strength among comparable individuals is body weight, and the practical conclusion is reached that variations in the strength of individuals can be met best by assessing the economic load to be carried and lifted as a definite fraction of the body weight.

In the second part of the investigation, the earlier researches into methods of weight carrying, to which reference has already been made, were repeated and amplified by study of variations in the disposition of the load. The previous results are in all essentials confirmed, and the tentative conclusion reached that 50 lb. for "conveniently disposed" loads and 40 lb. for "inconveniently disposed" loads is about the maximum physiologically economic load for women continually engaged in carrying.

Finally, in order to obtain a picture of existing practice a series of about 550 observations of the loads actually carried or lifted in different industries was made, the weight of each person being also taken so as to admit of a comparison between body-weight and load. For the purpose of studying the demands made on different classes of workers, the subjects tested were grouped according to whether they were young persons aged 14–16, young persons aged 16–18, or women over 18. It was found that the industries varied in order of sequence for each of these groups in respect not only of the weight of individual loads and the total load

moved *per diem*, but also of the body weights of the workers and of the ratio of load to body weight. An important distinction, however, is drawn between industries where the weight of the load is definitely fixed, and those where the load can be selected to suit the personal convenience of the operative. The conclusions reached are that in regard to fixed loads, the weights in present industrial practice are on the whole well within the capacity of women and adolescents, whilst in occupations where choice of the weight is available to the operative, women are usually self-protective, but young persons of both sexes, particularly males, are sometimes apt to attempt to lift and carry a load heavier than that for which they are adapted. The opinion is expressed that the weight of the individual load should not exceed 40 per cent. of the body weight for continuous, and 50 per cent of the body weight for intermittent or occasional carrying.

The special precautions to be observed in co-ordinating the results of these different lines of investigation scarcely need emphasising. Account for instance had to be taken of the wide range in strength and other physical attributes amongst women, of the effect of age, and particularly of the fact that the heavier and more strenuous occupations tend to attract the stronger women, so that any standard based on the requirements of the average industrial woman would be inapplicable to special occupations for which women of exceptional physique are recruited.

The main conclusions arrived at may be divided into two categories, the first relating to women (as represented by the average of those examined and exclusive, therefore, of those exposed to selective influences of the kind referred to), the second to adolescent girls. The authors state that according to the laboratory researches on physiological cost of carrying, the most economic load appears to be about 35 per cent of the body weight, though the actual percentage depends to a large extent on the mode of carriage On the other hand, the subjects in these experiments were purposely selected as untrained in any one method, and accordingly to suggest a limitation at this figure would appear to be unnecessarily stringent.

They point out that if the suggestion made in Part III—that the maximum loads should be 40 per cent. of the body weight for continuous and 50 per cent. for intermittent carrying—were adopted, these would correspond to 45 and 55 lb. according to the average physical data obtained in Part I. The final conclusion reached is that while the data, translated into actual weight, indicate that a load of about 45 lb. would appear to be the optium for continuous carriage, the body of the average healthy woman worker would not be in any way strained by a load not exceeding 50 lb., with a possible extension of 20 per cent. when the load is compact and easily handled so that it does not interfere materially with the gait and balance of the bearer.

In the case of adolescents, another factor must be taken into account, namely the plastic condition of the body and the risk of malformation and distortion. The authors think, therefore, that it would be unsafe to adopt the above percentages of body weight as a hard and fast standard, even though the adolescent would probably be physically capable of handling a load so assessed, and they suggest as an alternative a limit of 25 to 30 lb. for female young persons aged 14 to 16, and a limit of 40 lb for female young persons aged 16 to 18.

The Board desire to record their indebtedness to the members of the Committee on Physiology of Muscular Work, under whose general supervision the investigation was conducted, and particularly to Professor E P. Cathcart, F.R S., for his personal direction of the work.

November, 1927.

THE PHYSIQUE OF WOMEN IN INDUSTRY

(A Contribution towards the Determination of the Optimum Load.)

BY

E. P. CATHCART, F.R.S. AND E. M. BEDALE, M.A.,
C. BLAIR, M.B., K. MACLEOD, M.B.,* AND E. WEATHERHEAD, M.Sc.

With a Special Section by
SYBIL G. OVERTON, M.B., H.M. Medical Inspector of Factories.

CONTENTS.

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PART II. DETERMINATION OF OPTIMUM LOAD.

PART III. LIFTING OF LOADS BY WOMEN AND YOUNG PERSONS.

INTRODUCTION.

In spite of the age-long participation of women in all varieties of work, in spite indeed of the fact that in many of the more primitive societies woman was *the* worker and bearer of burdens, but little real interest has ever been taken in her physique. Despite the many so-called contributions to the elucidation of the problem of woman's capacity as a worker, there are very few anthropometric data available which will permit of a reasoned finding. Even for such elemental measurements as those of height and weight, the amount of material is strikingly small as compared with the masses of figures relating to males and young children of both sexes.

In 1925 the Industrial Fatigue Research Board was approached by the Home Office to see if they could grant assistance in determining the optimum weights to be carried by women engaged in industrial processes. Accordingly, the work which is dealt with in the following pages was begun in the hope that it might be possible to acquire some information which would permit of the assessment required.

A very similar enquiry had been completed for the War Office in the case of soldiers. Here, however, the technique and scope of the enquiry was relatively simple and limited, since both the method of load carrying and the type of muscular activity were uniform and the anthropometric data required were both abundant and readily available. In the case of women engaged in industry the problem is far more complicated. The loads vary, not only in weight but in size and in quality, many modes of carriage are adopted, although as a rule in any one industry the mode of carriage is fairly uniform, the types of muscular activity are very varied, the work is carried on in the most varied of environmental conditions and the amount of anthropometric data regarding women in industry was practically nil.

In order then to deal with the problem it was obvious that at least three lines of attack would require to be taken up simultaneously if an answer were to be obtained in a reasonable time :—

(1) Anthropometric data of women in industry (and suitable controls).

(2) The physiological cost of the various modes of carriage to the individual worker.

(3) The determination of the loads actually carried by women in industrial operations.

(1) The collection of the requisite anthropometric data was made from groups of women drawn from various factories (numbering 26) between Glasgow and London and from a limited number of unemployed women. As a control we examined the women students of the Glasgow Provincial Training College. The number of women examined in the course of the enquiry amounted to 4,366.

(2) As regards the physiological cost of carriage of the loads by the various methods adopted in factories, the methods used by Miss Bedale [1] and recorded in her report No. 29 in this series have been utilised and extended. These results will be found in Part II of this report.

(3) Finally, the Chief Inspector of Factories and the Senior Medical Inspector of Factories of the Home Office detailed Dr. Sybil Overton, H.M. Medical Inspector of Factories, to carry out a series of observations in the various factories throughout the country. Her report, which has been published in abstract in the Annual Report of the Home Office for 1926, will be found in full in Part III of this report.

PART I.—ANTHROPOMETRIC DATA.

Previous Work.

As already stated the amount of data available is not abundant. Quetelet [2] (1869) in his monumental work has recorded not only the heights and weights, but also the "force rénale" (lumbar pull), and "force des mains" (grip). In determining the weight he made due allowance for clothing. His results are given in the following table (Table I) (females only). (Mean of values obtained in examinations of years 1835 and 1840.)

TABLE I.

Age.	Height. metres.	Weight. kilos.	Force renale kilos.	Force des Mains. kilos. R.	L.
13 ..	1·400	32·5	43	11·0	8·1
14 ..	1 446	36·3	47	12·8	11·15
15 ..	1·488	40·0	51	15·0	14·1
16 ..	1·521	43·5	57	16·8	15·1
17 ..	1·546	46·8	63	20·7	18·2
18 ..	1·563	49·8	67	20·8	18·8
19 ..	1·570	52·1	71	21·75	19·5
20 ..	1·574	53·2	74	21·7	20·2
21 ..	—	54·3	76	—	—
22 .	—	54·8	78	—	—
23 .	—	55·2	80	24·45	21·8
24 .	—	—	—	—	—
25 ..	1·578	54·8	82	—	—
27 ..	—	55·1	83	25·6	23·1
30 ..	1·580	55·3	—	—	—
35 ..	—	—	83	—	—
40 ..	1·580	—	—	—	—

Roberts [3] (1878) also g
nent to the present enquiry
from any one class. His
weights are with clothes. H
bow. The following table
data.

TABLE II

Age.	Height		Weight.		Weight corrected for clothes by factor used in present enquiry	Pull.	
	ins.	cm.	lb.	kilo.	kilo	lb.	kilo.
13 .	57·77	146·67	87·0	39·46	37·65	22·3	10·12
14 ..	59·80	151·83	96·7	43·86	42·05	25·5	11·57
15 ..	60·93	154·70	104·8	47·54	45·72	29·6	13·43
16 .	61·75	156·78	112·7	51·12	49·31	31·8	14·42
17 ..	62·52	158·74	114·9	52·12	50·30	33·9	15·34
18 ..	62·44	158·54	117·7	53·39	51·57	38·9	17·65
19 ..	62·75	159·32	123·7	56·11	54·29	40·8	18·51
20 .	62·98	159·91	123·2	55·88	54·07	42·0	19·05
21 ..	63·03	160·03	121·2	54·98	53·16	41·9	19·01
22 ..	62·87	159·63	124·2	56·34	54·52	42·9	19·46
23 .	63·01	159·98	126·4	57·34	55·52	38·5	17·46
24 .	62·70	159·19	120·6	54·70	52·66	39·2	17·78
25–29 .	62·02	157·47	120·1	54·48	52·66	40 8	18·51
30–39 ..	—	—	121·0	54·89	53·07	46·2	20·96
40–59 ..	—	—	—	—	—	—	—
30–70 ..	61·15	155·26	—	—	—	—	—
50–70 ..	—	—	—	—	—	38·1	17·28

Pearson [4] (1897) in his chapter on variations in man and woman has furnished a large amount of very interesting information, although he only gives the mean values for a number of subjects of varying ages under 65. As some of the observations which he records are of considerable interest and value from an industrial point of view and have not been investigated by us, we give two of his tables (Tables III and IV) in detail including his male data for comparison.

TABLE III —*Galton's data used by Pearson.*

	Sex.	No.	Mean.	Stand. Dev.	Coeff Variation.
Stature (inches) aet. 23–51.	M. F.	811 770	67·9 (172·4cm.) 63·3 (160·7cm)	2·55 2·40	3·75 3·79
Height, sitting (inches) aet. 23–51.	M. F.	1013 775	36·0 (91·0cm.) 33·9 (86·1cm.)	1·41 1·21	3·91 3·58
Span (inches) aet. 23–51.	M. F.	811 770	69·9 (177·5cm.) 63·0 (159·9cm.)	3·06 2·77	4·38 4·39

TABLE III.—*contd.*

	Sex	No	Mean.	Stand Dev	Coeff. Variation
Breathing capacity (cub. inches) aet. 23–26.	M. F.	212 277	219 (3,588ccm.) 138 (2,261ccm.)	36·3 28·1	16·6 20·4
Strength of pull (pounds) aet. 23–26.	M. F.	519 276	74 (33·6 kilo.) 40 (18·1 kilo.)	11·10 7·73	15·0 19·3
Squeeze (strongest hand) (pounds) aet. 23–26.	M. F.	519 276	85 (38·6 kilo.) 52 (23·6 kilo.)	11·47 11·10	13·4 21·4
Swiftness of blow (feet per sec.) aet. 23–26.	M. F.	516 271	18·1 13·4	3·51 2·29	19·4 17·1
Keenness of sight (inches) aet. 23–26.	M. F.	398 433	25 (63·5 cm.) 24 (60·9 cm.)	5·92 7·73	28·68 32·21

TABLE IV.—*Cambridge data used by Pearson.*

	Sex.	No.	Mean.	S.D.	C. of V.
Stature (inches) ..	M. F.	1077 135	68·93 (175·0cm.) 63·82 (162·0cm.)	2·51 2·42	3·64 3·79
Weight (lb.) ..	M. F.	1071 137	154·04 (69·9kilo) 126·59 (57·4kilo)	16·51 13·99	10·72 11·05
Pull (lb.) ..	M. F.	1066 134	84·44 (38·3kilo) 49·13 (22·3kilo)	13·15 8·22	15·58 16·72
Squeeze (lb.) L.H. R.H.	M. F. M. F.	1056 134 1058 133	81·15 (36·8kilo) 53·30 (24·2kilo) 85·21 (38·6kilo) 56·29 (25·5kilo)	11·7 10·01 11·62 10·37	14·55 18·78 13·64 18·42
Eyesight L.E. (inches) R.E.	M. F. M. F	1041 130 1035 132	58·44 59·25 61·21 60·30	19·43 19·51 20·22 20·95	33·25 32·93 33·25 34·73

It is evident then from the co-efficients of variation in these tables that " women relatively are slightly more variable in stature and span, much more variable in breathing capacity, strength of pull, squeeze of hand and absolutely are much more variable in keenness of sight. They are less variable in sitting height and much less variable in swiftness of blow."

These results are substantiated by the data obtained by Pearson from a much more uniform source (Cambridge Students, age 19–30), and, as Table IV shows, women, with the exception of the sight of the left eye, "are in all cases sensibly more variable than men."

On the other hand, Pearson's data obtained from his English family measurements (adults under 65) would tend to show (see Table V) that the women as regards stature were slightly less variable than man, whereas their span was slightly more variable, and that finally in a group aged between 23 and 26 the females were both absolutely and relatively more variable.

TABLE V

	Sex.	Age	No.	Mean	S.D.	C. of V.
Stature (cm.)	M. F.	Under 65.	1000 1000	172·81 cm. 159·90 cm.	7·04 cm. 6·44 cm.	4·07 4·03
Span (inches)	M. F.	Under 65	1000 1000	69·09 in. 62·02 in.	3·17 in. 2·88 in.	4·59 4·63
Weight (kilos.)	M. F.	— 23–26	520 276	64·86 kilo. 55·34 kilo.	4·54 kilo. 4·60 kilo.	10·37 13·37

Pearson is manifestly of the opinion that there is a definite tendency for the female to be more variable and he would ascribe this tendency as due in the main "to a relatively less severe struggle for existence."

Harris and Benedict [5] (1919), in their biometric study of basal metabolism, have collated all the original data, adults all ages (males 16 to 63 and females 16 to 74) of the Carnegie Nutrition Laboratory and, as Table VI shows, for their limited and selected numbers women would seem to be as regards stature both absolutely (as measured by the standard deviation) and relatively (as measured by the co-efficient of variation) less variable than men, whereas as regards body weight (nude) they are both absolutely and relatively more variable.

TABLE VI.

	Sex.	No.	Mean.	S.D.	C. of V.
Stature (cm.) . .	M. F.	136 103	172·96±0·44 161·96±0·34	7·59±0·31 5·19±0·24	4·39±0·18 3·20±0·15
Weight (kilo.)	M. F.	136 103	64·10±0·60 56·48±0·76	10·30±0·42 11·49±0·54	16·06±0·67 20·35±1·00

In the Medical Research Council Report, No. 84 (1924), Dr. Lucy D. Cripps [6] gives a record of her application of the Air Force Physical Efficiency tests to men and women and incidentally some data applicable to our present enquiry. The

women utilised were either students or civil servants. Table VII gives a summary of the *appropriate* data.

TABLE VII.—Group I, Polytechnic (Students); II, Somerset House (Civil Servants); III, Bedford College (Students); and IV, Air Force (fit men).

	Group.	No.	Mean.	S.D.	C. of V.
Age (years)	I	232	20·52±0·101	2·29	11·16
	II	124	26·34±0·466	7·69	29·21
	III	115	21·13±0·113	1·79	8·46
	IV	950	23·80±0·101	4·62	19·42
Height Standing (cms.)	I	226	164·54±0·180	4·02	2·44
	I	125	159·92±0 356	5·90	3·69
	III	71	163·63±0·513	6·41	3·92
	IV	950	174·81±0·137	6·28	3·59
Weight (kilos)	I	226	56·423±0·243	5·42	9·61
	II	125	53·18±0·463	7·67	14·43
	III	70	53·41±0·595	7·39	12·64
	IV	950	63·48±0·158	7·24	11·41
Chest (cms.)	I	218	73·46±0·134	2·93	3·99
	IV	950	86·29±0·102	4·65	5·39

As a general summary of the position of anthropometric data in Britain the final report of the Anthropometric Committee of the British Association [7] (1883) from its 53,000 records (female records under 400) is generally accepted. The figures are as follows:—

TABLE VIIA.

	Height.	Weight.	Ratio stature.	Age at which maturity is reached.
Average Male ..	1·712 m.	70·5 kilo	16	23
Average Female	1·592 m.	55·8 kilo	14·88	20

It is interesting to note that the stature male : female ratio of 16 : 14·88 is very close to that calculated for the Belgian data of Quetelet of 16 : 14·99.

As regards the relative strengths of the average male and female, the Committee came to the conclusion that the female was a little more than half as strong as the male. Galton [8] (1885) from his careful examination of 4,726 males and 1,657 females (all adults) concluded that "the female differs from the male more conspicuously in strength than in any other particular."

Scope of Present Investigation.

As our aim was to obtain a good representative sample of the women who were engaged in industrial processes of all kinds, involving all types of work from light sedentary to heavy, we made our selection from a series of workers on a line drawn from Glasgow to London. This took in a good sample of the great industrial areas of Scotland, the Midlands and the South ; 4,366 women were accurately examined by us, and of these 3,949 are utilised in this report, and in addition certain measurements were made by Dr. Overton of women scattered throughout the country. Table VIII gives a list of the trades in which the women examined were employed.

Group 1—3,076 English and Scottish women engaged in industrial work. (Factory women).

Group 2—413 Glasgow women who had spent several years in factory work but who had been unemployed for at least one year. (Unemployed.)

Group 3—460 Scottish Women Students attending the Provincial Training College for Teachers in Glasgow. (College women.)

Group 4—417 women in various factories in England partially examined by Dr. Sybil G. Overton.

TABLE VIII.

List of Industries.

Industry.	*District.*	*No. of Firms.*
Printing	Glasgow	1
Engineering and Metal Working	1 Glasgow 5 Midland	6
Textile	1 Glasgow. Carpets 2 Lancs. Cotton	3
Warehouse	Glasgow	2
Bakery	Glasgow	1
Clothing	Glasgow	1
Chemical	Glasgow	1
Laundry	1 Glasgow 1 London	2
Shoes	Midlands	1
Pottery	Midlands	2
Bricks	Midlands	1
Confectionery	1 Glasgow. Sweets 1 London. Sweets and Tea 1 London. Jam	3
Soap	London	1
Bottling	London	1
		26

Methods of Investigation.

COLLECTION OF DATA.

Each girl examined was given a card (see below) and on this was noted :—her name and occupation, her age taken to the

NAME,		Occupation,	No ,
Age, M S W. Birth Place,		Race F.,	M ,
Weight	Height (without boots or shoes),		
How clothed			
Length of Arm (axilla to finger tips),	Distance Finger Tips from Ground (arms at side, no boots or shoes),		
Pull (lumbar) kilo ,	1	2	3
Grip (hand) ,,	1 R. L.	2 R. L.	3 R. L.
Crush (arms) ,,	1	2	3
Years (Country)			
Years (Industry)			
Notes —			

nearest month, the race of her father and mother, whether she was single, married or a widow, and if one of the last two whether she had any children, whether she had spent any of her life in the country, her industrial history, whether she played games or took any regular exercise, any obvious deformities. It may be thought that the enquiry was somewhat inquisitorial, but the information was obtained as privately as possible, it was never refused and so far as we know never resented. Each of the subjects, it may be remarked, was a volunteer. No pressure direct or indirect was brought to bear on any employee in order to make her subject herself to examination. Indeed the element of competition in the strength tests made many girls eager to be tested.

The measurements noted were :—

Weight.—This was taken without shoes, light heel-less slippers being provided to prevent any embarrassment. In the circumstances it was of course necessary to weigh the women with clothes on , assessments, however, were made of the weight of clothing worn by the average worker, and as a result 4 lb. were deducted from the gross weights obtained. In the case of Group 3 the college women, who at the time of the examination all wore regulation gymnasium dress, 3 lb. were deducted from the gross weights.

Height (*standing*).—This was taken without boots or shoes, but wearing the light heel-less slippers provided.

Length of Arm.—This was measured with a steel tape from the axilla to the finger tips, care being taken in every instance about the placing of the end of the tape in the axilla.

Distance of finger tips from ground —This was measured without boots and shoes, the arms by the side, and the distance being measured from the tip of the third finger. Throughout this section this measurement is referred to as *finger tip distance.*

The *Strength Tests* used require a little more detailed explanation.

At first sight it may appear that it is a very simple and easy thing to determine the strength of any individual by allowing the subject to use some such simple instrument as a hand dynamometer, and many experiments have, it is true, been made, using either the original pattern of Collin or the improved type of Smedley. Other dynamometers have been designed to test the muscle groups of the back and legs. The drawback to the utilisation of these simple methods is that the measurement of strength was a purely volitional effort on the part of the subject.

Martin and Lovett [9] (1915) realised this and introduced another method of determination which to some extent countered this objection. The significance of Martin's work lay in the fact that his method measured the breaking point of a muscle or muscle group ; thus he measured the force required to overcome maximal resistance. He devised his method to test children so as to overcome the need of positive effort. In his earliest work he tested no less than 40 muscle groups although later he evolved a shorter procedure which he found gave as good a final result. The method of Martin has been used to test the strength of children [10] (Martin, E. G., 1918) of adult males [11] (Martin and Rich, 1918), of college women [12] (Mosher and Martin, 1918), and of factory workers both male and female [13] (Martin, E. G., 1920).

The method was utilised in England by Muscio [14] (1922) in an investigation of adolescent males. He found that the results obtained in carrying out the test were partly a function of the observer. The method therefore fails to be of general use by a variety of investigators, although reliable enough for estimating the relative strength of a number of subjects examined by the same observer.

We had intended using a modified Martin test, but in view of the findings of Muscio we reverted to the older type of dynamometer. In each test three trials were allowed. We discarded the first and utilised for our data the mean value of trials 2 and 3. As regards the tests eventually employed, we selected three as giving some indication of the power of groups of muscles commonly used in industrial processes.

1. " *Lumbar Pull.*" Although chiefly intended to test the muscles of the back and the thighs, this test gives some indication of the general muscular strength as the muscles of the arms and shoulders are also brought into play.

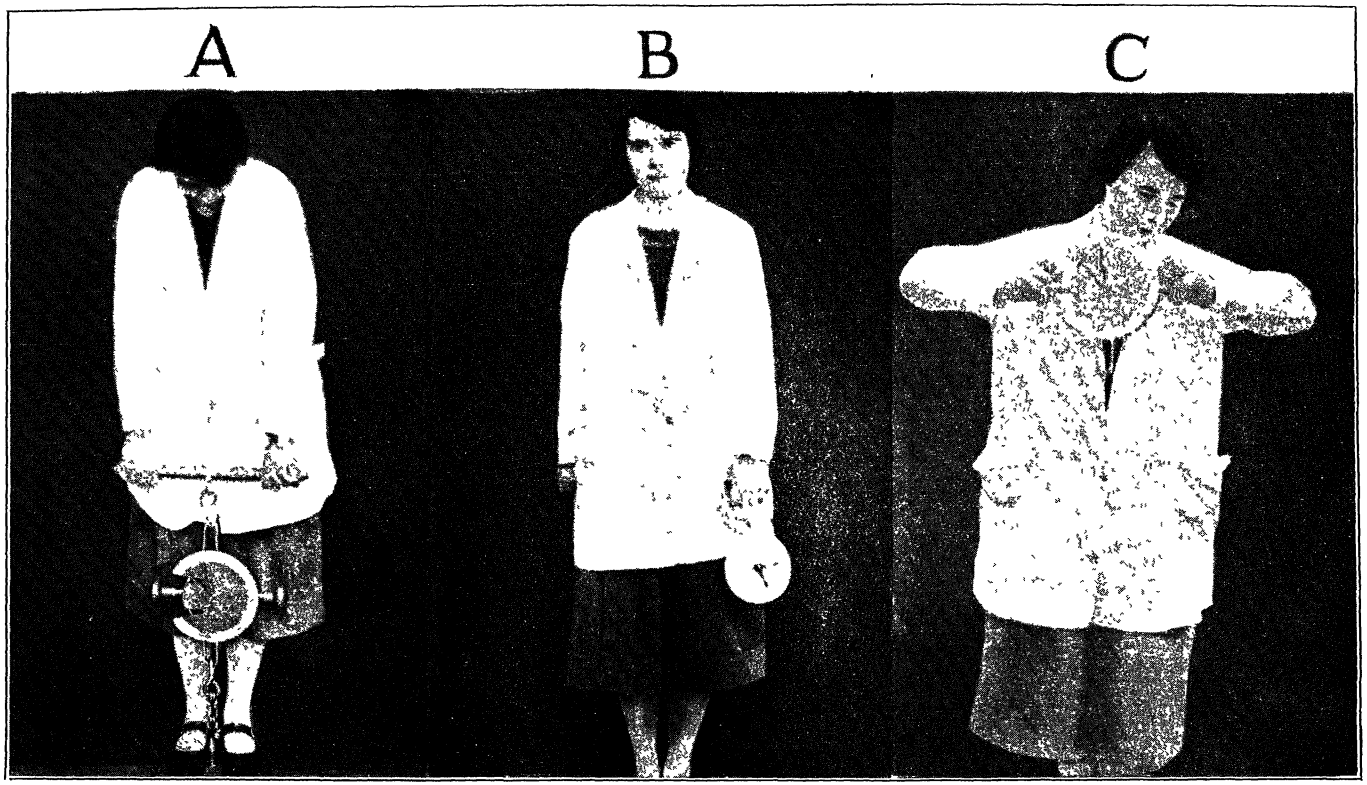

FIG 1 Method of Measuring, A, Pull, B, Grip, C, Crush

In order to carry out the test the subject stands on a block of wood of suitable size attached by a chain to the lower end of the dynamometer. The upper end of the dynamometer is connected by a hook with a horizontal handle which allows of a comfortable grip. By altering the number of links in the chain connecting the dynamometer with the standing block, the dynamometer is easily adjusted to a constant level for subjects of varying physique. The constant level used throughout this investigation was that the handle of the dynamometer should be at finger tip level when the subject was standing erect with her arms at her sides. The weight of the dynamometer complete was 2·2 kilos. See fig I*a*.

As the machine used was a self-registering one there was no need to keep up the tension, after the maximal pull was made, until a reading could be taken. In spite of full explanation of this being made to the subjects it was often noted that the women pulled to a certain level and maintained that position; yet, when encouraged to do so, could sometimes exert a pull a hundred per cent. greater. In this respect they differed very markedly from the few men who were examined. These always gave one good strong pull without any maintenance of tension. Due attention was given in collecting the data to this peculiarity in women.

2. "*Hand grip.*" Smedley's type of dynamometer was used with the adjustable handle. It is essential, if measurements of value are to be made of a variety of subjects with varying sized hands, that a dynamometer with adjustable handle should be used. The grip was adjusted to suit the hand of each subject. In carrying out the test the subject stood erect and held her hand down by her side. The grip of both right and left hands was tested, but in the analysis of the data the grip of the stronger hand was used. Fig. I*b*.

3. "*Arm crush.*" The same dynamometer was used as in the lumbar pull, but without the foot rest and the chain-on handle. In carrying out this test we found by preliminary experiment that a standard attitude must be adopted if comparative results of value were to be obtained. In practice we also found that it was often difficult to get the subjects to adopt the proper attitude. The subject should stand erect and hold the dynamometer with the bent arms at shoulder level, the hands being in the prone position. Although the half prone position of the hands would perhaps seem to be the natural one to adopt, this position was not found to be so effective as the completely prone position. The subject then pushes inwards on the dynamometer, particular care being taken to see that it does not come into contact with the chest wall Fig. I*c*. The reasons for applying this particular test are given on p 28.

We found that this was for the majority of the girls a difficult test, although sometimes after one or two very poor attempts, the subject would "get the knack of it" and double her previous

record with apparently no increased effort. Some subjects obtained their best results with hollowed chests, others with the chest thrown forward and the shoulders well back. This is evidently a matter of individual muscle or muscle group control.

Each of the three tests, as already mentioned, was made three times on every subject. Following the conclusions of Vernon [15] (1924) the subjects were allowed to rest for four minutes between each of the nine tests and whenever possible they were allowed to sit down for this period. A number of girls were taken at a time and tested in rotation. Under these conditions there was a natural development of the spirit of keen competition. We think that the results we obtained with these tests do give an excellent index of the maximal effort which the subjects tested could exert. The only possible fallacy in the collection of the data, and we do not from our experience think it is a serious one, is that, owing to the number of girls to be tested, they could not all be examined at one fixed hour in the day. It would seem, however, reasonable to suppose that if any error arises from this cause in the number of girls examined it will be to a great extent neutralised.

TREATMENT AND CLASSIFICATION OF DATA.

As regards the treatment and classification of the data obtained, the following procedure was adopted :—

Group 1.—*Factory women.* The cards of the English and Scottish women were treated together and separated into age groups. Up to the age of 26 these groups are yearly, e.g. age group 15 years includes all girls of $14\frac{6}{12}$ to $15\frac{5}{12}$ inclusive. In

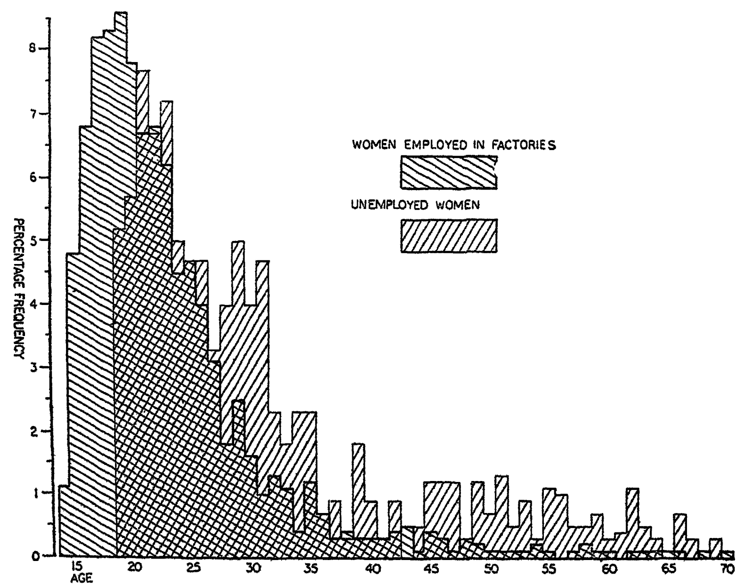

FIG. II. Percentage age frequency of Employed Factory Women and Unemployed Women.

the later ages several years are included in one group in order to give sufficient numbers for statistical treatment. The groups thus obtained (with the exception of age group 14 which only includes girls from $14\frac{0}{12}$ to $14\frac{5}{12}$) vary in size from 104 to 269. Fig. 2 gives the percentage frequency of the women of this group and of the following, the unemployed, group.

After determining the constants for each age group the cards were well shuffled and a disinterested person picked out four random samples each of 200 cards. The same constants were again worked out for these samples.

Group 2.—*Unemployed women.* Each age group here included several years. One random sample was taken.

Group 3.—*College women.* Three yearly age groups were taken and ages 22 and 23 were grouped together. Because of the limited range of age in this homogenous group no random sample was worked out.

Group 4.—*Dr. Overton's data.* Here the collection of data was not made on the special cards utilised for the other three groups nor was the age noted exactly to the month. The treatment and classification of this group was therefore a little different. Three groups were made—(1) young persons aged 14–18, (2) women 19–23, and (3) women 24–29.

Statistical Treatment.

As it would be impossible, even if it were desirable, to keep in view the measurements of each individual examined in the course of the investigation resort must be had to statistical treatment. In order that the significance of the numerical data be more readily appreciated, the various statistical measures adopted have been dealt with a little more fully than may by many be deemed necessary. It is of course impossible to give in the short space at our disposal a brief treatise on statistical method, nor indeed are we competent to do so. But we hope in the remarks which follow we have made reasonably clear the why and wherefore for the adoption of certain measurements and that they will render the data thus stated more intelligible.

A MEASURES OF GENERAL TENDENCY AND VARIABILITY.

Obviously if one wishes to discover the general trend of a whole series of observations a representative measure must be sought. The most commonly employed of representative measures is the *arithmetic mean* or average value. This mean is simply the sum of all the observations of any particular measurement (or variate) divided by their number. As this mean is therefore affected by all the individual measurements it is truly a representative measure, but it gives no indication of the dispersion of the series, i.e. the extent of the deviation of the individual observations from the average or mean value. It is obviously important to know whether all the measurements of the series lie close to the mean or whether they are much scattered and deviate widely from it. The

measure of variation or scatter most commonly employed is the *Standard Deviation* (S.D. or σ). In the determination of this value the larger deviations are given proportionately greater weight by squaring all the deviations, summing these squares and then dividing by the number of deviations to obtain the mean square deviation. The square root of this value is the standard deviation.

Both the arithmetic mean and the standard deviation are absolute values. But if the variability of two series of different units is to be compared, it will obviously be unsatisfactory to compare merely their standard deviations unless the means be alike. Some measure therefore must be used which takes into account both the standard deviation and the size of the mean, i.e. it is necessary to reduce two standard deviations to a comparable basis by stating them as percentages of their respective means Such a measure is the *Coefficient of Variation* (v).

$$\text{C. of V.} = \frac{100 \times \text{S.D.}}{\text{M.}}$$

This coefficient is essential for comparing the variability of one group with that of another.

Another measure of variability or scatter is the *Probable Error* (p.e.). The probable error of any variate is half the difference between the two values of the variate which cut off 25 per cent. of the observations from either end of the frequency distribution; hence in a symmetrical distribution the odds are even that any observation should have a deviation from the mean either greater or less (in absolute value) than the probable error. In the following tables each measure is given $\pm$ its probable error.

$$\text{P.E. of Mean} = \cdot 6745\, \sigma/\sqrt{n}$$
$$\text{P.E. of S.D.} = \cdot 6745\, \sigma/\sqrt{2n}$$
$$\text{P.E. of C. of V.} = \frac{\cdot 6745\, v}{\sqrt{2n}} \times \left\{1+2\left(\frac{v}{100}\right)^2\right\}^{\frac{1}{2}}$$

B. Measures of Correlation and Regression.

The foregoing measures of general tendency and variability give information only about each separate series of phenomena. We often wish to know whether there is any relationship and therefore apparent causal connection existing between two series of observations. There are many fallacies in making such a comparison, as Pearson has pointed out, but if due care be exercised in the choice of data such a comparison often provides information of real importance. If it can be shewn that in a large number of instances two variates, e.g. the height and weight of a man, or his strength and weight, always tend to move in the same, or it may on occasion be in a diametrically opposite,

direction, it is generally held that some measure of relationship or correlation exists. This relationship can be estimated statistically by "measures of correlation and regression." There are at least two measures available; the correlation coefficient (r) and the correlation ratio (η).* When the means of the measurements of the two series of values to be compared, put down in appropriate rows and columns, "arrays" as they are technically called, lie in a straight line, the method of the correlation coefficient is utilised and in the case where they follow a curvilinear course, the correlation ratio is employed.

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* The correlation ratio is the ratio of the Standard Deviation of the weighted means of the arrays to the Standard Deviation of the variate.

The correlation ratio of x on $y = \eta_{x\,y} = \dfrac{\sigma_{\bar{x}\,y}}{\sigma_x}$ where $\sigma_{\bar{x}\,y}$ = S.D. of weighted means of the values of x for a given y, and σ_x = S.D. of the variate x

Similarly, the correlation ratio of y on $x = \eta_{y\,x} = \dfrac{\sigma_{\bar{y}\,x}}{\sigma_y}$ where $\sigma_{\bar{y}\,x}$ = S.D. of weighted means of the values of y for a given x, and σ_y = S.D. of the variate y.

In the tables which follow, η is corrected to allow for the influence of the number of arrays, using the following formula given by Pearson in Biometrika XIV, p. 417.

$$\text{Corrected } \eta^2 = \frac{\text{observed } \eta^2 - (K - 3)/N}{1 - (K - 3)/N}$$

K = number of arrays of variate y (above).
N = number of observations

The probable error of η is given by $\cdot 6745\ (1 - \eta^2)/\sqrt{N}$

The correlation coefficient is obtained by finding the mean of the products of individual pairs of deviations (x^1y^1) and dividing this figure by the product of the two standard deviations σ_x and σ_y

$$r = \frac{Sx^1y^1/N}{\sigma_x\,\sigma_y} \quad \text{(where S denotes sum of all pairs of } x^1 \text{ and } y^1\text{)}$$

The p.e. of $r = \cdot 6745\ (1 - r^2)/\sqrt{N}$

Correlation may be regarded as significant only if r is not less than p.e. $\times$ 3. When this is so, the chances are 22 to 1 that the true value lies within these limits If $\sqrt{N}/\cdot 6745 \times \frac{1}{2}\sqrt{\eta^2 - r^2}$ is less than 3, effective linearity may be assumed (η here is the observed value)

Since there are two sets of arrays there must be two regression curves and corresponding to these two coefficients of regression. The coefficient of regression δf x on y measures the mean linear change in one series (x) corresponding to a unit change in the other series y, and is equal to $\dfrac{r\,\sigma_x}{\sigma_y}$

By plotting the regression lines one can predict the mean value of x for a given y. If the regression is linear

$$(x - \bar{x}) = r\,\frac{\sigma_x}{\sigma_y}\,(y - \bar{y})$$

$\bar{x}$ and $\bar{y}$ are the means of the variates x and y.

Similarly to find mean y for a given x: $(y-\bar{y}) = r\,\dfrac{\sigma_y}{\sigma_x}\,(x-\bar{x})$

The purpose of making the two determinations of the coefficient and the ratio is merely to estimate their closeness of value and hence to decide the closeness of the approximation of these values to a straight line or, as it is commonly put, to a true linear regression. In the event of the regression being strictly or approximately linear we conclude that given the value of one variate we can predict the average of the other variate with a degree of accuracy that depends both on the scatter of the values about the mean of the arrays and on the number of single values comprised in the average.

The values of η lie between $+1$ and 0, and of r between $+1$ and -1. If $r = 1$ correlation is perfect and has sometimes been held to amount to causation (in data derived from the living organism this is practically an unknown quantity); but even perfect correlation need not imply causation in the usual sense of the term. If $r = 1$ or even if $\eta = 1$ it means that every value of x has only one value of y corresponding to it. Causation can never be proved by correlation alone. If $r = 0$ the series are taken as independent. If it is positive, this means that an increase in one variate is accompanied by an increase in the other; if negative, by a decrease in the other. The correlation coefficient therefore shows what the correlation ratio does not, i.e., whether the two series vary in the same or opposite directions. The purpose of calculating both r and η is to find if r be near η or not; if it be near, linear regression may be assumed.

In the present investigation in each age group the factors or variates correlated with each other were height, weight, pull, grip, crush, and also height with finger tip distance. In the total and random samples of factory and unemployed women, age was correlated with each of the above factors. In the cards of the College women the range of age was too small profitably to allow of this.

In the data collected by Dr. Overton correlations were worked out between height, weight and load carried, and in the two groups of women (above the age of 18) a fourth factor, years employed was also utilised.

The following were the units of grouping adopted:—

Weight	2 kilogrammes.
Height	2 centimetres.
Finger Tip Distance..	1 centimetre.
Lumbar Pull ..	5 kilogrammes.
Crush	2 ,,
Grip	2 ,,
Age (in random samples)	2 years.

Results.

GROUP I.—EMPLOYED WOMEN.

Our main group was of course that of the factory women actively employed. The sample of over 3,000 selected was believed to be sufficiently large to enable us to make generalisations on the type of women engaged in industrial pursuits, as the work investigated varied from the purely sedentary to really severe muscular work.

By far the heaviest work noted was that done in a Chemical Works (Glasgow) and a Brick Works in the Midlands. Next to these come the Engineering Works, the Bottling Works and Laundries and some of the heavy lifting and carrying in the Potteries.

So far as heavy work is concerned the remainder of the trades might well be considered together, for, except in a few operations, all the work was more or less sedentary. The work therefore was tiring in the same way that continued standing or walking is tiring.

It is a commonplace that the introduction of machinery a century ago wrought a revolution in the industrial world, and that the development and specialisation of machinery has largely relegated human labour to the task of "machine minding." Little distinction then can be drawn between tea packing and carpet making, when in both trades the essential operations consist of minding a machine. This also holds true in the lighter engineering trades where in some operations even the "feeding" of the machine is done mechanically.

On the other hand it must not be deduced that the extensive use of machinery has abolished skilled labour. For the most part it has only altered the type of dexterity. Speed is undoubtedly the keynote of modern industry and to turn a shoe at a machine revolving at a very high rate requires as much dexterity as to turn it by hand.

In the list of trades given in Table VIII there are six firms listed as metal working and engineering. Separately they were :—

(1) Nut and Bolt Works—Glasgow.
(2) Nut and Bolt Works—Midlands.
(3) Chain Works ,,
(4) Hollow Ware Works ,,
(5) Pen Works ,,
(6) Telephone Works ,,

In Works 1, 2 and 3 the work was fairly heavy, the machines being operated by hand or foot levers, moreover the work was done in noisy workshops. A number of the girls examined in workshop 2 were, however, employed on very light engineering work in well lighted and well ventilated shops. In Works 4 there was a good deal of heavy work involved in the scouring and

beating of kettles and in enamelling the inside of heavy pans which the girls had to lift and twist and throw in order to obtain a smooth surface.

In Works 5 and 6 the work done was for the most part sedentary.

In the bottling factory the girls worked in cellars at machines operated by hand or foot levers. In the two laundries much of the work done consisted in the packing and sorting of clothes, although a certain number of the girls were employed operating fairly heavy machines.

The two most interesting industries from our point of view were the chemical works in Glasgow and the brick works in the Midlands already referred to.

In the chemical works 40 girls were employed, all doing navvy work, their hours were from 6 a.m. to 6 p.m. with two hours off for meals. All the women and girls worked with ease and barefooted. The movements involved seemed to be of a type which ensured muscular development and poise as without exception their carriage and physique was literally remarkable. We were told that the mothers and grandmothers of many of the women employed had done the same work before them. No girls were taken on under sixteen and, astonishing as it may seem, they were drawn from the district immediately surrounding the factory, one of the worst in Glasgow. As evidence of what these workers were capable of we saw one woman who shovelled 20–25 tons of crude borite per day lifting it to a height of about 2 feet 6 inches. Five girls who shovelled crystals from evaporating pans into trucks, which, after filling, they wheeled for a considerable distance along very imperfect rails, had an average combined output per group of 6 tons per day.

In the case of the brick works there were two main types of work (*a*) setting and drawing, and (*b*) brick moulding. In (*a*) the girls filled and emptied the ovens, the work done being very heavy. Each girl carried three or four large bricks for a distance of 70 to 80 yards. These girls were allowed themselves to determine how many bricks they would carry. The majority selected four at a time. The bricks weighed 26¾ lb. each and were generally held in a spiral (overlapping) pile by the left arm, the bottom brick supported on a padded belt of sacking worn round the hips. One girl spent her time loading up the others. Each girl therefore carried a weight only 5 lb. short of a hundredweight. In (*b*) brick moulding, the work was done by older women who worked barefoot. They slammed the clay into wooden moulds then placed the moulded brick to dry on the steam heated stone floor. Some women wheeled barrows containing 4–4½ cwt. of bricks. The good carriage of the girls in this factory was also very remarkable. It is of interest to note (see Table XX later) that the strength of the girls in the chemical and brick works was very much higher than in any of the other trades.

TABLE IX.—*Factory Investigation—Physical Measurements.*

Age Group.	No. in Group.	Weight. Mean Weight (kilos)	Weight. S.D.	Weight. C. of V.	Height. Mean Height (cms).	Height. S D.	Height. C of V	Finger Tip Distance. Mean Distance (cm.).	Finger Tip Distance. S D.	Finger Tip Distance. C. of V.
14–$14^{5}/_{12}$	34	38·81 ±0·77	6·63 ±0·54	17 08 ±1·43	151·04 ±0·89	7·71 ±0·63	5·10 ±0·41	56·40 ±0·44	3·83 ±0·31	6·78 ±0·53
$14^{6}/_{12}$–$15^{5}/_{12}$	152	44·00 ±0·35	6·34 ±0·25	14·42 ±0·57	155·66 ±0·33	6·01 ±0·23	3·86 ±0·15	58·55 ±0·17	3·06 ±0·12	5·22 ±0·19
$15^{6}/_{12}$–$16^{5}/_{12}$	213	46·28 ±0·28	6·04 ±0·20	13·06 ±0·43	156·62 ±0·26	5·64 ±0·18	3·60 ±0 11	59·06 ±0·15	3·25 ±0·11	5·50 ±0·18
$16^{6}/_{12}$–$17^{5}/_{12}$ .. .	257	47 75 ±0·26	6·12 ±0·18	12·81 ±0·39	156·97 ±0·24	5·78 ±0·17	3 68 ±0·10	58·99 ±0·14	3·43 ±0·10	5·81 ±0·18
$17^{6}/_{12}$–$18^{5}/_{12}$	259	50·19 ±0·27	6·49 ±0·19	12·93 ±0·39	158·18 ±0·22	5·36 ±0·16	3·39 ±0·10	59·72 ±0·14	3·42 ±0·10	5·73 ±0·16
$18^{6}/_{12}$–$19^{5}/_{12}$	269	50·93 ±0·30	7·38 ±0·21	14·49 ±0·43	158·45 ±0·24	5·92 ±0·17	3·73 ±0 10	59·66 ±0·14	3·33 ±0·10	5·59 ±0·16
$19^{6}/_{12}$–$20^{5}/_{12}$ . . .	247	50 12 ±0 29	6·77 ±0·21	13·51 ±0·42	157·52 ±0·25	5·72 ±0·17	3·63 ±0·11	59·65 ±0·15	3·42 ±0·10	5·73 ±0·17
$20^{6}/_{12}$–$21^{5}/_{12}$	210	49·99 ±0·29	6·29 ±0·21	12·58 ±0·42	158·02 ±0·26	5·52 ±0·18	3·49 ±0·12	59·63 ±0·16	3·35 ±0·11	5 61 ±0·18
$21^{6}/_{12}$–$22^{5}/_{12}$	211	49·94 ±0·31	6·58 ±0·22	13·18 ±0·43	157·95 ±0·29	6·21 ±0·20	3·93 ±0·13	59·90 ±0·16	3·44 ±0·11	5·74 ±0·18
$22^{6}/_{12}$–$23^{5}/_{12}$	197	49 60 ±0 35	7 19 ±0·24	14·49 ±0·50	157·27 ±0·26	5·49 ±0·19	3·49 ±0·12	59·56 ±0·15	3·14 ±0·11	5·27 ±0·19
$23^{6}/_{12}$–$24^{5}/_{12}$	141	50·72 ±0·42	7 38 ±0·30	14·56 ±0·59	157·80 ±0·34	6·06 ±0·24	3·84 ±0 16	59·95 ±0·20	3·45 ±0·14	5·76 ±0·22
$24^{6}/_{12}$–$25^{5}/_{12}$	146	49·50 ±0·40	7·23 ±0·29	14·60 ±0·58	156·79 ±0·35	6·22 ±0 25	3·96 ±0·16	59·61 ±0 20	3·66 ±0·14	6·14 ±0·24
$25^{6}/_{12}$–$26^{5}/_{12}$	124	50·52 ±0·53	8·77 ±0·38	17·35 ±0·77	157·10 ±0·41	6·74 ±0·29	4·29 ±0·17	59·60 ±0·21	3·52 ±0·15	5·91 ±0·26
$26^{6}/_{12}$–$28^{5}/_{12}$	164	51·26 ±0·44	8·31 ±0·31	16·22 ±0·61	157·84 ±0·37	7·06 ±0·26	4 47 ±0 17	59·78 ±0·20	3·80 ±0·14	6·35 ±0·24
$28^{6}/_{12}$–$30^{5}/_{12}$	116	50·11 ±0 44	6·96 ±0·31	13·88 ±0·63	156·49 ±0·38	6·08 ±0·27	3·88 ±0·18	59·33 ±0·22	3·45 ±0·15	5·82 ±0·27
$30^{6}/_{12}$–$40^{5}/_{12}$	232	52·94 ±0·46	10·36 ±0·32	19·57 ±0 63	157·28 ±0·25	5·71 ±0·18	3·63 ±0·11	59·53 ±0·15	3·31 ±0·10	5·56 ±0·17
$40^{6}/_{12}$–$55^{5}/_{12}$	104	54·10 ±0·60	9·06 ±0·42	16·76 ±0·79	156·60 ±0·34	5·17 ±0·24	3·30 ±0·16	59·35 ±0·26	3·93 ±0·18	6·63 ±0·31

Table IX which deals with the physical measurements of Group 1, the factory women, shows as regards weight that there is a very definite and steady increase from the age of 14 to 18 or 19, thereafter until the last age groups of $40\frac{6}{12}$ to $55\frac{5}{12}$ is reached the weight remains approximately constant although there is evidence from the data of the penultimate age group $30\frac{6}{12}$ to $40\frac{5}{12}$ that the increase has begun during this decade. This tendency to increase of weight at or about the menopause is of course a well-known condition. The tendency to increase is already shown (Table IX) in the penultimate group where the slight increase in both absolute and relative variation is probably due to variation in physiological function, i.e., the weights are less uniform, and does not vitiate the conclusion drawn from the rise in the mean. As regards height our data shows that amongst these girls and women there is a sharp jump between 14 and 15 then a slower increase up to 18 or 19, and that thereafter, as might be expected, there is no definite evidence of increase in stature. The groups as the coefficients of variation show may be regarded as fairly homogenous.

Baldwin [16] in his report on physical growth and school progress gives a tabular summary of all anthropometric work on his subject up to 1914 (see Tables X and XI abbreviated from Baldwin's data). The general conclusion to be drawn from this survey of earlier measurements is that height increases in women up to about 19 years, and weight increases fairly rapidly up to about the age of 17.

As has been said, we carried out a series of measurements of the distance of the finger tips from the ground. The object of making this particular measurement was to obtain, if possible, some data which might permit of a more scientific statement of the optimum average height of working bench. Naturally it is not the finger tip distance but the elbow height which governs the working level but as a measure which can be easily and accurately made the finger tip distance excels the elbow height. The elbow height can be determined from the finger tip height by adding on the average length of forearm as determined by Pearson. Pearson and Lee [17] found the mean length of the forearm to be approximately 16·5 inches. Therefore if we add this figure to the heights as determined in the present study we obtain elbow height. Our data show that after about the age of 18 the distance of the finger tips from the ground remains practically constant. Indeed after the age of 15 there is no marked increase. This, associated with the uniformity of the height data should render easy and economical the provision of working benches of suitable height.

When the strength tests of this factory group arranged again in order of age are considered in Table XII it will be noted in the first place from a general examination of the statistical constants that in these tests we have met with a much wider range of variation. All three coefficients of variation must be

TABLE X.—*Height in cms.*

Ages in Years	Roberts, 1878 England, all Classes (30,000+)		Anthrop Com, 1880 England, Schools, Military and Naval Colleges (29,405).		Peckham, 1882 America		Peckham, 1882 *American* (1 M, 1 F)		British Association *Report*, 1883		Shuttleworth, 1884 England General Population		Stevenson, 1887 English speaking people from England and America		Greenwood, 1890 American, white (2,619)		Barnes, 1892 Oakland, Cal (4,956)		Porter, 1893. St Louis (16,295 M., 18,059 F).	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F.
14	150 70	151 89	144 5	146 8	—	150 1	150 6	148 3	150 6	151 9	157 5	154 76	151 38	152 07	143 76	145 87	151 6	155 4	148 1	150 6
15	158 09	154 76	150 6	151 9	—	156 5	158 8	154 9	158 0	154 7	162 6	156 85	158 16	154 97	148 84	153 19	156 9	157·2	154 9	154·9
16 .	163 35	156 85	158 0	154 7	—	161 3	167 9	157 2	163 3	156 7	166 4	158 80	164 23	156 64	158 50	158 75	163 8	159 2	160 2	157 4
17	168 25	158 80	163 3	156 7	—	162 1	175 0	159 0	168 1	158 7	168 9	158 60	168 15	158 01	162 31	159 77	170 4	159 2	165 1	159 2
18	170 08	158 60	168 1	158 8	—	162 1	177 5	160 0	169 9	158 5	170 2	159 39	169 70	157 96	164 59	160 76	171 7	160 5	—	159·5
19	170 92	159 39	170 2	158 5	—	162 1	180 1	161 3	170 9	159 3	170 8	159 97	—	—	169 32	163·07	—	—	—	158·5
20	171 50	159 97	170 9	159 5	—	—	—	—	171 4	159 7	171 4	160 10	—	—	—	—	—	—	—	—
21	171 78	160 10	171 4	160 0	—	—	—	—	171 7	160 0	—	159 69	—	—	—	—	—	—	—	—
22	171 91	159 69	171·7	160 0	—	—	—	—	—	—	—	160 05	—	—	—	—	—	—	—	—
23	171 40	160 05	—	—	—	—	—	—	—	—	—	159 26	—	—	—	—	—	—	—	—
24	172 01	159 26	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
25	172 09	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	172 16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
27 .	172 52	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	171 96	—	—	—	—	—	—	—	—	—	172 1	157 53	—	—	—	—	—	—	—	—
29	172 39	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
34 .	172 44	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
39	172 95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
45	172 62	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
47	172 52	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
49	171 22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
51 ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE X.—*cont.*—*Height in cms.*

Ages in Years.	Hanna, 1893. Oberlin College (500 F Students).		Porter, 1894 St Louis (15,525 M, 16,527 F.)		West, 1894 Worcester (3,250).		Boas, 1897 American (2,386 M, 1,967 F)		Boas, 1897. American (45,151 M, 43,298 F).		Gilbert, 1897 Iowa (50 M, 50 F.)		Smedley, 1900. Chicago (2,788 M, 3,471 F)		Hastings, 1902 Nebraska (7,700 M, 7,069 F)		Baldwin, Chicago, 1910 (400 M, 500 F.).	
	M.	F.	M	F.	M	F.	M.	F.	M.	F	M	F	M	F	M	F	M	F.
14	—	150 50	148 59	150 83	154 2	153 7	154 61	153 87	152·40	153 49	156·7	156 7	151 94	153 64	150·75	152·91	159 00	158·01
15	—	—	154·89	155·04	162 3	157 0	162 00	156 89	159 72	156 49	164 3	160 8	158 09	156 85	157 89	156 51	165 00	159·00
16	—	159 87	160 27	157 53	165 9	158·5	165 99	157 20	164 90	158 04	169 4	160 8	164 06	158 32	163 42	157 63	167 01	161·01
17	—	155 80	165·12	159 33	168 4	159 5	168 55	159 10	168 91	159 13	173·2	163 8	167 89	159 28	169·67	159 10	168·45	162·00
18	—	157·51	170·40	159·41	169 9	159 0	—	—	171 07	—	174 2	164 1	171 25	159 44	170·76	159 46	—	—
19	—	160 30	—	158 44	171·2	159 3	—	—	—	—	175 2	164 1	—	—	171·50	159 79	—	—
20	—	162 31	—	159·39	174·0	159 0	—	—	—	—	—	—	—	—	171 91	160 53	—	—
21	—	163 91	—	159 97	170 4	159 3	—	—	—	—	—	—	—	—	—	—	—	—
22	—	164 80	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
23	—	166 90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
24	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
27	—	168 50	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	—	170 41	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
29	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
45	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
47	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
49	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
51	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE XI.—*Weight in kilos.*

Ages in Years	Bowditch, 1875, Boston (13,691 M., 10,904 F.)		Roberts, 1878, England All Classes		Peckham, 1881, Milwaukee		British Association Report, 1883, English		Shuttleworth, 1884, England General Population		Greenwood, 1890, American, White (2,055)		Barnes, 1892, Oakland, Cal.		Hanna, 1893, Oberlin (500 students)		Hanna, 1893, Oberlin, (1,600 students)		Smedley, 1900, Chicago (2,788 M., 3,471 F.)		Hastings, 1902, Nebraska (7,700 M., 7,069 F.).	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F.	M	F.
14	43 13	44 72	41 81	43 95	43 54	44 36	41 81	43 95	42 04	43 95	39 75	41 69	44 09	44 63	—	—	—	—	42 79	44 31	39 72	42 91
15	48 67	48 22	46 68	47 63	49 54	48 13	46 68	48·18	46 59	48 31	42·47	45 50	49·13	49 50	—	39 79	—	39 45	48·10	48 27	46 95	46 70
16	54 99	50 90	54 09	51 22	55 49	50 27	54 13	51 40	53 40	51 40	50·57	50 52	55 27	49 90	—	41 59	—	40·59	53 35	50·76	52 89	50·38
17	57 94	52 49	59 49	52 22	59 27	51 49	59 09	52 27	61 36	52 49	54·09	53 23	59 86	53 49	—	43 80	—	44 40	57 51	52 50	56 81	50 44
18	60 26	52 35	62·45	53 49	62 63	51 13	62 45	55 04	64 77	55 04	57 54	54 05	62 58	53 77	—	47 40	—	47 40	61 42	53 04	59 24	50 15
19	—	—	63 45	56 22	—	—	63 45	56 27	65 31	56 27	62 19	54 65	—	—	—	50 11	—	50 09	—	—	61 70	51 43
20	—	—	65 13	55 99	—	—	65 13	56 09	65 90	56 09	—	—	—	—	—	52 81	—	52 77	—	—	61 08	52·26
21	—	—	65 99	55 09	—	—	65 99	55 36	66 45	55 36	—	—	—	—	—	56 08	—	—	—	—	—	—
22	—	—	66 77	56 45	—	—	—	—	67 04	56 09	—	—	—	—	—	—	—	57 09	—	—	—	—
23	—	—	67·18	57 45	—	—	—	—	67 58	56 40	—	—	—	—	—	58 03	—	58 59	—	—	—	—
24	—	—	67 27	54 81	—	—	—	—	68 18	54 90	—	—	—	—	—	61 63	—	60 86	—	—	—	
25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
26	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	64 31	—	—	—	—
27	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	65 81	—	—	—	—
28	—	—	—	—	—	—	—	—	68 72	54 54	—	—	—	—	—	67·85	—	—	—	—	—	—
31	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	72 36	—	—	—	—	—	—
32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	71 13	—	—	—	—
36	—	—	—	—	—	—	—	—	69 31	54 90	—	—	—	—	—	—	—	—	—	—	—	—
46	—	—	—	—	—	—	—	—	70·45	53 90	—	—	—	—	—	—	—	—	—	—	—	—
48	—	—	—	—	—	—	—	—	71 58	47 27	—	—	—	—	—	—	—	—	—	—	—	—

TABLE XII.—*Factory Investigation—Strength Tests.*

Age Group	No. in Group.	Hand Grip. Mean Grip (kilos).	Hand Grip. S D	Hand Grip. C of V	Lumbar Pull Mean Pull (kilos)	Lumbar Pull S D	Lumbar Pull C of V	Crush Mean Crush (kilos)	Crush S D.	Crush C of V.
$14-14^{5}/_{12}$	34	20·95 ±0·49	4·23 ±0·35	20·19 ±1·70	63·54 ±1·69	14·63 ±1·20	23·02 ±1·98	17·07 ±0·64	5·52 ±0·45	32·35 ±2·93
$14^{6}/_{12}-15^{5}/_{12}$	152	23·42 ±0·26	4·71 ±0·18	20·10 ±0·80	72·26 ±0·83	15·25 ±0·59	21·10 ±0·85	19·23 ±0·35	6·47 ±0·25	33·64 ±1·43
$15^{6}/_{12}-16^{5}/_{12}$	213	25·27 ±0·20	4·40 ±0·14	17·42 ±0·59	78·63 ±0·72	15·47 ±0·51	19·68 ±0·66	20·71 ±0·26	5·68 ±0·19	27·44 ±0·96
$16^{6}/_{12}-17^{5}/_{12}$	257	25·67 ±0·18	4·39 ±0·13	17·09 ±0·52	79·57 ±0·58	13·73 ±0·41	17·26 ±0·52	21·82 ±0·26	6·17 ±0·18	28·26 ±0·89
$17^{6}/_{12}-18^{5}/_{12}$	259	26·64 ±0·20	4·76 ±0·14	17·88 ±0·55	83·73 ±0·62	14·82 ±0·44	17·70 ±0·53	23·48 ±0·26	6·20 ±0·18	26·39 ±0·84
$18^{6}/_{12}-19^{5}/_{12}$	269	26·75 ±0·19	4·53 ±0·13	16·92 ±0·51	85·05 ±0·67	16·31 ±0·47	19·18 ±0·57	24·05 ±0·27	6·61 ±0·19	27·47 ±0·86
$19^{6}/_{12}-20^{5}/_{12}$	247	26·50 ±0·19	4·45 ±0·14	16·80 ±0·53	83·59 ±0·67	15·55 ±0·47	18·60 ±0·58	23·13 ±0·26	6·08 ±0·18	26·28 ±0·84
$20^{6}/_{12}-21^{5}/_{12}$	210	27·23 ±0·24	5·16 ±0·17	18·95 ±0·65	85·27 ±0·78	16·83 ±0·55	19·74 ±0·67	23·20 ±0·29	6·31 ±0·21	27·20 ±0·95
$21^{6}/_{12}-22^{5}/_{12}$	211	26·86 ±0·26	5·53 ±0·18	20·58 ±0·70	85·22 ±0·87	18·79 ±0·62	22·05 ±0·76	22·80 ±0·30	6·55 ±0·22	28·72 ±1·01
$22^{6}/_{12}-23^{5}/_{12}$	197	27·08 ±0·25	5·30 ±0·18	19·57 ±0·69	84·32 ±0·86	17·81 ±0·61	21·13 ±0·74	22·56 ±0·28	5·83 ±0·20	25·84 ±0·94
$23^{6}/_{12}-24^{5}/_{12}$	141	27·59 ±0·28	4·90 ±0·20	17·75 ±0·72	88·04 ±0·93	16·35 ±0·66	18·57 ±0·76	24·25 ±0·38	6·74 ±0·27	27·77 ±0·19
$24^{6}/_{12}-25^{5}/_{12}$	146	26·56 ±0·27	4·91 ±0·19	18·47 ±0·75	85·54 ±1·01	18·04 ±0·71	21·09 ±0·86	23·11 ±0·38	6·75 ±0·27	29·20 ±1·24
$25^{6}/_{12}-26^{5}/_{12}$	124	27·08 ±0·30	5·03 ±0·22	18·56 ±0·82	86·84 ±1·08	17·89 ±0·77	20·60 ±0·91	23·55 ±0·43	7·16 ±0·31	30·41 ±1·42
$26^{6}/_{12}-28^{5}/_{12}$	164	27·59 ±0·26	4·99 ±0·19	18·07 ±0·69	85·17 ±1·00	18·92 ±0·70	22·21 ±0·86	23·62 ±0·39	7·44 ±0·28	31·51 ±1·28
$28^{6}/_{12}-30^{5}/_{12}$	116	26·36 ±0·28	4·52 ±0·20	17·16 ±0·77	82·52 ±1·11	17·69 ±0·78	21·44 ±0·99	22·12 ±0·41	6·50 ±0·29	29·38 ±1·42
$30^{6}/_{12}-40^{5}/_{12}$	232	27·19 ±0·22	4·78 ±0·15	17·56 ±0·56	86·98 ±0·95	21·35 ±0·67	24·55 ±0·81	23·47 ±0·29	6·56 ±0·21	35·80 ±1·25
$40^{6}/_{12}-55^{5}/_{12}$	104	25·97 ±0·33	4·91 ±0·23	18·91 ±0·92	80·94 ±1·42	21·50 ±1·01	26·56 ±1·32	19·45 ±0·36	5·44 ±0·25	28·00 ±1·41

regarded as high but arranged in order of merit the " hand grip " takes precedence of " lumbar pull " and " crush " is definitely more variable. In a sense this is what one might expect as the order of precedence is that of ordinary activities. Almost all workers have, willy nilly, been trained to grasp things large or small therefore the technique of the test is one to which the hand and fingers are already accustomed. The majority of the workers have also had to exert their strength in vertical lifts from the floor but the technique of the pull to be exerted on a dynamometer handle is somewhat different from that in common use Finally, few workers have any practical experience of a crushing movement of the arms It was for this reason that the test was adopted. It was realised that both the grip and the pull are, so to speak, natural movements and it was desired to obtain if possible a test which would eliminate practice and skill.

As regards " grip " it will be noted that this increases up to about the age of 18 and then remains astonishingly constant. Even here, in comparison with the other two strength tests, the difference between women in the third and fourth decades of life is not marked. With " pull " there would seem to be a relatively sharp rise in the power, or perhaps the control, of the great muscle groups of the body up to the age of 19. Again the " pull " remains fairly constant until the sharp drop at the last group is reached Finally the " crush " shows a steady rise until the age of 18 is reached and it too remains wonderfully constant until the final group is reached. Although in each of these tests there is a definite fall when the fourth decade is reached the decline is not such as to permit the conclusion that there is a marked deterioration. In view of the fact that the majority of these women have spent the best part of their lives working hard it is rather a matter for surprise that they have retained their physical vigour so perfectly. The " machine " is far from being worn out.

We now turn to the consideration of whether there is any inter-relationship between these various physical measurements. The calculation of the correlation coefficients and the correlation ratios will be found in Tables XIII, XIV, XV and XVI. The correlation ratio must in theory be greater than the correlation coefficient, and is so before any correction is applied. In practice, as will be observed in our tables, the correction sometimes makes it less than r and thus indicates that η and r are probably equal within the limits of sampling.

Weight Correlations.—Table XIII. The inspection of this table shows very clearly the various correlation coefficients weight and height, weight and pull, weight and grip, weight and crush. If it be borne in mind that a correlation of unity may be taken to show perfect relationship, then as regards weight and height the correlation especially in the first age group is very high and remains fairly good with the exception of age group 26 up to age group 30. Thereafter as might have been anticipated

TABLE XIII.—*Factory Investigation—Weight Correlations*

Age Group	No. in Group.	Correlation Coefficients (r)				Correlation Ratios (η).			
		Weight and Height	Weight and Pull	Weight and Grip	Weight and Crush	Height on Weight	Pull on Weight	Grip on Weight	Crush on Weight
14–$14^{5}/_{12}$ ..	34	+·86±·029	+·69±·061	+·77±·048	+·54±·082	+·82±·037	+·73±·054	+·76±·050	+·53± 083
$14^{6}/_{12}$–$15^{5}/_{12}$ ..	152	+·52±·040	+·27±·051	+·42±·045	+·31±·049	+·54±·039	+·29±·050	+·41±·045	+·22±·052
$15^{6}/_{12}$–$16^{5}/_{12}$ ..	213	+·52±·034	+·46±·037	+·41±·038	+·31±·042	+·51±·034	+·44±·037	+·40±·039	+·28±·043
$16^{6}/_{12}$–$17^{5}/_{12}$ ..	257	+·54±·030	+·37±·036	+·49±·032	+ 42±·035	+·58±·028	+·45±·034	+·51±·031	+·44±·034
$17^{6}/_{12}$–$18^{5}/_{12}$ ..	259	+·48±·032	+·29± 038	+·40±·035	+·29±·038	+·47±·033	+·31±·038	+ 40± 035	+·32±·038
$18^{6}/_{12}$–$19^{5}/_{12}$ ..	269	+·58±·027	+·28±·038	+·31±·037	+·24±·039	+·56±·028	+·29±·038	+·25±·039	+·22±·039
$19^{6}/_{12}$–$20^{5}/_{12}$ ..	247	+ 50±·032	+·28±·040	+ 38±·037	+·28± 040	+·52±·032	+·26±·040	+·44±·035	+·34±·038
$20^{6}/_{12}$–$21^{5}/_{12}$ ..	210	+·48±·036	+·36±·041	+·37±·040	+·22±·044	+·49±·036	+·45±·037	+·46±·037	+·31±·042
$21^{6}/_{12}$–$22^{5}/_{12}$ ..	211	+ 51± 035	+·12±·046	+·26±·043	+ 28±·043	+·53±·033	+·22±·044	+·16±·045	+·21±·044
$22^{6}/_{12}$–$23^{5}/_{12}$ ..	197	+ 55± 034	+·46±·038	+·39±·041	+·32± 043	+·57±·032	+·42±·040	+·43±·039	+·27±·045
$23^{6}/_{12}$–$24^{5}/_{12}$.	141	+·45±·045	+·30±·052	+ 27±·053	+·16±·055	+·50±·043	+·20±·055	+·22±·054	+·14±·056
$24^{6}/_{12}$–$25^{5}/_{12}$ ..	146	+·52± 041	+·40± 047	+ 43±·045	+·24±·053	+·52±·041	+·35±·049	+·43±·045	+·16±·055
$25^{6}/_{12}$–$26^{5}/_{12}$ ..	124	+·36±·053	+·30±·055	+·37±·052	+·25±·057	+·35±·053	Indeterminate	Indeterminate	Interdeminate
$26^{6}/_{12}$–$28^{5}/_{12}$ ..	164	+ 54±·037	+·30±·048	+·30±·048	+·34±·047	+ 63±·032	+·39±·045	+·39±·045	+·42±·043
$28^{6}/_{12}$–$30^{5}/_{12}$ ..	116	+ 42±·052	+·27±·058	+·43±·051	+·23±·059	+·47±·049	+·33±·056	+ 38±·054	+·34±·056
$30^{6}/_{12}$–$40^{5}/_{12}$ ..	232	+·39±·038	+·24±·042	+·41±·037	+·20±·043	+·39±·038	+·15±·043	+·39±·038	+·11±·044
$40^{6}/_{12}$–$55^{5}/_{12}$ ..	104	+·34±·059	+·23± 063	+ 39±·056	+ 27± 061	+·36±·057	+ 33± 059	+·30±·060	+·41±·055

TABLE XIV.—*Factory Investigation—Height Correlations.*

Age Group.	No in Group	Correlation Coefficients (*r*) Height and Finger Tip Distance.	Height and Pull.	Height and Grip.	Height and Crush	Correlation Ratios. (η) Finger Tip Distance, on Height.	Pull, on Height.	Grip, on Height.	Crush, on Height.
$14\text{–}14^{5}/_{12}$ ..	34	+·87±·015	+·66±·066	+·75±·050	+·71±·058	+·83±·035	+ 65±·067	+·64±·068	+·70±·060
$14^{6}/_{12}\text{–}15^{5}/_{12}$ ..	152	+·78±·022	+·33±·049	+·44± 044	+·41±·046	+·78±·020	+·35±·048	+·44±·044	+·39±·053
$15^{6}/_{12}\text{–}16^{5}/_{12}$ ..	213	+·76±·020	+·42±·038	+·43±·038	+·34±·041	+·76±·020	+·40±·039	+·41±·039	+·29±·042
$16^{6}/_{12}\text{–}17^{5}/_{12}$ ..	257	+·79±·016	+·35±·037	+·43±·034	+·41±·035	+·80± 015	+ 31±·038	+·43±·034	+·44±·034
$17^{6}/_{12}\text{–}18^{5}/_{12}$ ..	259	+ 72±·020	+·24±·040	+·36±·037	+·32±·038	+·73±·020	+·19±·041	+·34±·037	+·28±·039
$18^{6}/_{12}\text{–}19^{5}/_{12}$ ..	269	+·75±·018	+·33±·037	+·36±·036	+·39±·035	+·74± 018	+·35±·036	+·35±·036	+·39±·035
$19^{6}/_{12}\text{–}20^{5}/_{12}$ ..	247	+·77±·018	+·30±·039	+·38±·037	+·35±·038	+·76±·018	+·32±·039	+·40±·036	+·33±·038
$20^{6}/_{12}\text{–}21^{5}/_{12}$ ..	210	+·76±·020	+·19±·045	+·32±·042	+·33±·041	+·76±·019	+·21±·045	+·34±·041	+·30±·042
$21^{6}/_{12}\text{–}22^{5}/_{12}$ ..	211	+·75±·021	+·16±·045	+·37±·040	+·29±·042	+·74±·021	+·10± 046	+·35±·041	+·30±·042
$22^{6}/_{12}\text{–}23^{5}/_{12}$ ..	197	+·77±·019	+·35±·042	+·28±·044	+·38±·041	+·76±·020	+·47±·038	+·39±·041	+·38±·041
$23^{6}/_{12}\text{–}24^{5}/_{12}$ ..	141	+·78±·022	+·31±·051	+·38±·049	+·38±·049	+·76±·024	+·38±·049	+·39±·048	+·40±·048
$24^{6}/_{12}\text{–}25^{5}/_{12}$ ..	146	+·82±·018	+·39±·047	+·39±·047	+·30±·051	+·83±·018	+·43±·045	+·43±·045	+·31±·050
$25^{6}/_{12}\text{–}26^{5}/_{12}$ ..	124	+·81±·021	+·28±·056	+·41±·050	+·30±·055	+·80±·022	+·25±·057	+·43±·049	+·34±·053
$26^{6}/_{12}\text{–}28^{5}/_{12}$ ..	164	+·84±·015	+·21±·050	+·37±·045	+·38±·045	+·83±·016	+·19±·051	+·39±·045	+·41±·044
$28^{6}/_{12}\text{–}30^{5}/_{12}$ ..	116	+·76±·026	−·01±·063	+·30±·057	+·26±·058	+·74±·028	Indeterminate	+·17±·061	+·21±·060
$30^{6}/_{12}\text{–}40^{5}/_{12}$ ..	232	+·72±·022	+·32±·040	+·31±·040	+·33±·039	+·71±·022	+·32±·040	+·36±·038	+·33±·040
$40^{6}/_{12}\text{–}55^{5}/_{12}$ ..	104	+·69±·035	+·18±·064	+·30±·060	+·23± 063	+·74±·030	+·36±·057	+·41±·055	+·38±·057

TABLE XV.—*Factory Investigation—Lumbar Pull Correlations.*

Age Group.	No in Group.	Correlation Coefficients (r)				Correlation Ratios (η)			
		Weight and Pull.	Height and Pull	Pull and Grip.	Pull and Crush.	Pull, on Weight	Pull, on Height.	Grip, on Pull.	Crush, on Pull.
$14–14^{5}/_{12}$ ..	34	+·69±·061	+·66±·066	+·73± 055	+·50± 087	+·73±·054	+·65±·067	+·77±·047	+·57±·078
$14^{6}/_{12}–15^{5}/_{12}$ ..	152	+·27±·051	+·33±·049	+·62±·034	+·57±·037	+·29±·050	+·35±·048	+·70±·028	+·59±·036
$15^{6}/_{12}–16^{5}/_{12}$ ..	213	+·46±·037	+·42±·038	+·53±·034	+·44±·037	+·44±·037	+·40±·039	+·54±·033	+·42±·038
$16^{6}/_{12}–17^{5}/_{12}$ ..	257	+·37±·036	+·35±·037	+·55±·030	+·53±·030	+·45±·034	+·31±·038	+·57±·029	+·55±·030
$17^{6}/_{12}–18^{5}/_{12}$ ..	259	+·29±·038	+·24±·040	+·53±·031	+·44±·034	+·31±·038	+·19±·041	+·54±·030	+·40±·035
$18^{6}/_{12}–19^{5}/_{12}$ ..	269	+·28±·038	+·33±·037	+·49±·031	+·61±·026	+·29±·038	+·35±·036	+·52±·030	+·60±·027
$19^{6}/_{12}–20^{5}/_{12}$ ..	247	+·28±·040	+·30±·039	+·53± 031	+·49± 033	+·26±·040	+·32±·039	+·52±·031	+·49±·033
$20^{6}/_{12}–21^{5}/_{12}$ ..	210	+·36±·041	+·19±·045	+·60±·030	+·48±·036	+·45±·037	+·21±·045	+·59±·030	+·44±·037
$21^{6}/_{12}–22^{5}/_{12}$ ..	211	+ 12±·046	+·16±·045	+·66±·026	+ 56± 032	±·22±·044	+·10±·046	+·63±·028	+·54±·033
$22^{6}/_{12}–23^{5}/_{12}$ ..	197	+·46±·038	+·35±·042	+·61±·030	+·44±·039	+·42±·040	+·47±·038	+·63±·029	+·42±·040
$23^{6}/_{12}–24^{5}/_{12}$ ..	141	+·30±·052	+·31±·051	+·67±·032	+·40±·048	+·20± 055	+ 38±·049	+·72±·027	+·41±·047
$24^{6}/_{12}–25^{5}/_{12}$ ..	146	+·40± 047	+·39± 047	+ 62±·035	+·51± 041	+·35±·049	+ 43±·045	+·62±·034	+·54±·040
$25^{6}/_{12}–26^{5}/_{12}$ ..	124	+·30±·055	+·28±·056	+·67±·034	+·59±·040	Indeterminate	+·25±·057	+·62±·037	+·62±·038
$26^{6}/_{12}–28^{5}/_{12}$ ..	164	+·30±·048	+·21± 050	+ 61±·033	+ 52± 038	+·39±·045	+·19±·051	+·66±·030	+·60±·034
$28^{6}/_{12}–30^{5}/_{12}$ ..	116	+·27±·058	−·01±·063	+·45±·050	+·55±·044	+·33± 056	Indeterminate	+·42±·052	+·50±·047
$30^{6}/_{12}–40^{5}/_{12}$ ..	232	+·24± 042	+·32±·040	+·58±·030	+·52±·032	+·15± 043	+·32±·040	+·57±·030	+·48±·034
$40^{6}/_{12}–55^{5}/_{12}$ ..	104	+·23±·063	+·18±·064	+ 52±·048	+·54±·047	+·33±·059	+·36±·057	+·55±·046	+·58±·044

TABLE XVI.—*Factory Investigation—Hand Grip Correlations.*

Age Group.	No in Group	Correlation Coefficients. (r)				Correlation Ratios. (η)			
		Weight and Grip.	Height and Grip	Pull and Grip.	Grip and Crush.	Grip, on Weight	Grip, on Height.	Grip, on Pull.	Crush, on Grip.
14–$14^{5}/_{12}$ ..	34	+·77±·048	+·75±·050	+·73±·055	+·72±·055	+·76±·050	+·64±·068	+·77±·047	+·77±·056
$14^{6}/_{12}$–$15^{5}/_{12}$ ..	152	+·42±·045	+·44± 044	+·62±·034	+·57±·037	+·41±·045	+·44±·044	+·70±·028	+·58±·037
$15^{6}/_{12}$–$16^{5}/_{12}$ ..	213	+·41± 038	+·43±·038	+·53±·034	+·41±·039	+·40±·039	+·41±·039	+·54±·033	+·42±·038
$16^{6}/_{12}$–$17^{5}/_{12}$ ..	257	+·49±·032	+·43±·034	+·55±·030	+·48±·033	+·51±·031	+·43±·034	+·57±·029	+·49±·032
$17^{6}/_{12}$–$18^{5}/_{12}$ ..	259	+·40±·035	+·36±·037	+·53±·030	+·44±·034	+·40±·035	+·34±·037	+·54±·030	+·43±·034
$18^{6}/_{12}$–$19^{5}/_{12}$ ..	269	+·31±·037	+·36±·036	+·49±·031	+·45±·033	+·25±·039	+·35±·036	+·52±·030	+·47±·032
$19^{6}/_{12}$–$20^{5}/_{12}$ ..	247	+·38±·037	+·38±·037	+·53±·031	+·46±·034	+·44±·035	+·40± 036	+·52±·031	+·46±·034
$20^{6}/_{12}$–$21^{5}/_{12}$ ..	210	+·37±·040	+·32±·042	+·60±·030	+·49±·035	+ 46± 037	+·34± 041	±·59±·030	+·47±·036
$21^{6}/_{12}$–$22^{5}/_{12}$ ..	211	+·26±·043	+·37±·040	+·66±·026	+·58±·031	+·16± 045	+·35±·041	+·63±·028	+·56±·032
$22^{6}/_{12}$–$23^{5}/_{12}$ ..	197	+·39±·041	+·28±·044	+·61±·030	+·39±·041	+·43± 039	+·39±·041	+·63±·029	+·40±·041
$23^{6}/_{12}$–$24^{5}/_{12}$ ..	141	+·27± 053	+·38±·049	+·67±·032	+·46± 045	+ 22± 054	+·39±·048	+·72±·027	+·46±·045
$24^{6}/_{12}$–$25^{5}/_{12}$ ..	146	+·43± 045	+·39±·047	+·62±·035	+·44±·045	+·43±·045	+·43±·045	+·62±·034	+·38±·048
$25^{6}/_{12}$–$26^{5}/_{12}$ ..	124	+·37±·052	+·41±·050	+·67±·034	+·47±·047	Indeterminate	+·43± 049	+·62±·037	+·52±·044
$26^{6}/_{12}$–$28^{5}/_{12}$ ..	164	+·30±·048	+·37±·045	+·61±·033	+·49±·040	+ 39±·045	+ 39± 045	+·66±·030	+·46±·042
$28^{6}/_{12}$–$30^{5}/_{12}$ ..	116	+·43±·051	+·30± 057	+·45±·050	+·31±·051	+·38±·054	+·17±·061	+·42±·052	+·37±·054
$30^{6}/_{12}$–$40^{5}/_{12}$ ..	232	+·41±·037	+·31±·040	+·58±·030	+·44±·036	+·36±·038	+·36±·038	+·57±·030	+·47±·034
$40^{6}/_{12}$–$55^{5}/_{12}$ ..	104	+·39±·056	+·30±·060	+·52±·048	+·58±·044	+·30±·060	+·41±·055	+·55±·046	+·59±·043

from the natural tendency to put on weight with age, the correlation becomes definitely reduced. With weight and pull the correlation with the exception of age groups 14 and 16 is not good. Weight and grip are definitely better but weight and crush are on the whole even lower than weight and pull.

Height Correlations.—Table XIV. As one might have expected there is a high degree of interdependence between the height of the subject in all age groups and the distance of her finger tips from the ground. Between height and pull in spite of the fact that the height of the dynamometer handle was adjusted correctly for each subject the correlation is definitely poor being in fact in age group 28–30 negative and insignificant. Height and grip and height and crush both show about the same degree of interdependence and that not high. These findings again are substantiated by the correlation ratios.

Lumbar Pull Correlations.—Table XV. Weight and pull and height and pull have already been considered. The two following sets of correlations between the strength tests do, however, both show fairly high correlations, pull and grip being slighter higher than pull and crush. Pull and grip are higher on the whole than any other set of correlationns except height and finger tip distance. This of course simply means that strength in one set of muscles implies the probability of an "all round" muscular strength and adeptness.

Hand Grip Correlations.—Table XVI. The only correlation to be considered here is that of grip and crush. Considering the fact that the one test calls into operation a set of muscle movements to which the subject is well used and the other necessitates a new, unpractised and not particularly easy operation, the correlation between the two is astonishingly good. The inference is, of course, that for these relatively gross operations more depends on the muscular development of the subject than on her skill of manipulation.

These results are shown perhaps more clearly and sharply in Figs. III to X.

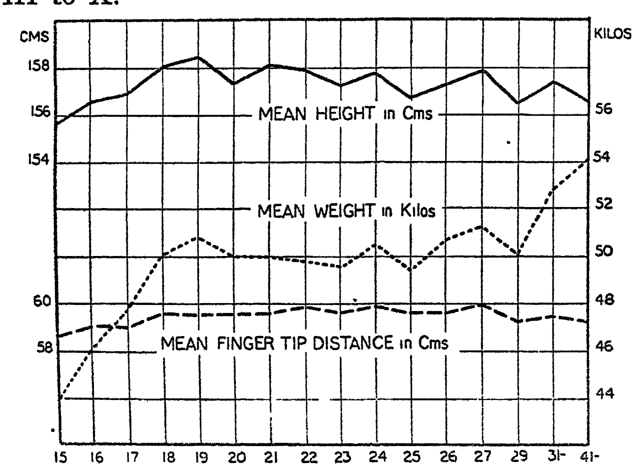

FIG III. Factory Women, physical measurements of different Age Groups.

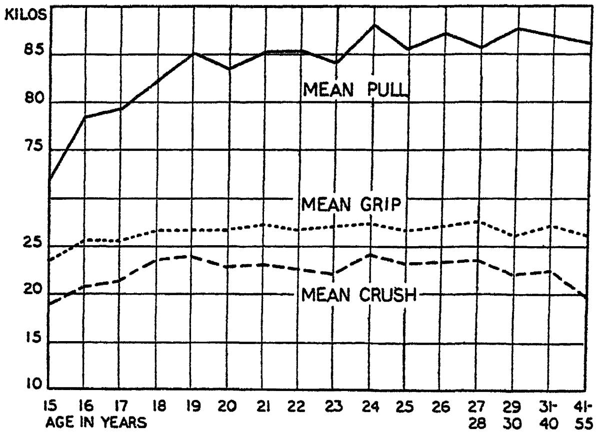

FIG IV. Factory Women, Pull, Grip and Crush of different Age Groups.

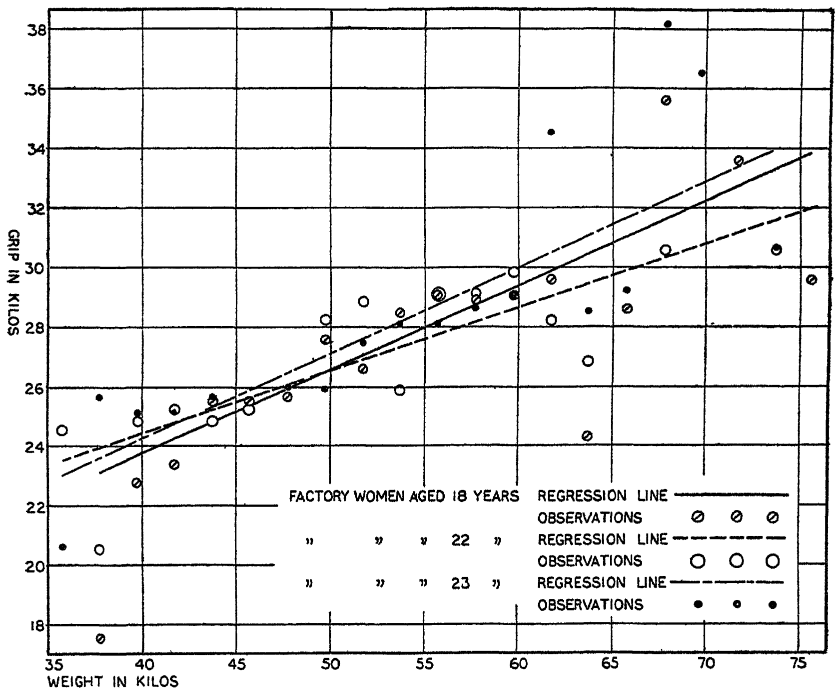

FIG. V. Factory Women, regression line and observations. Grip on Weight.

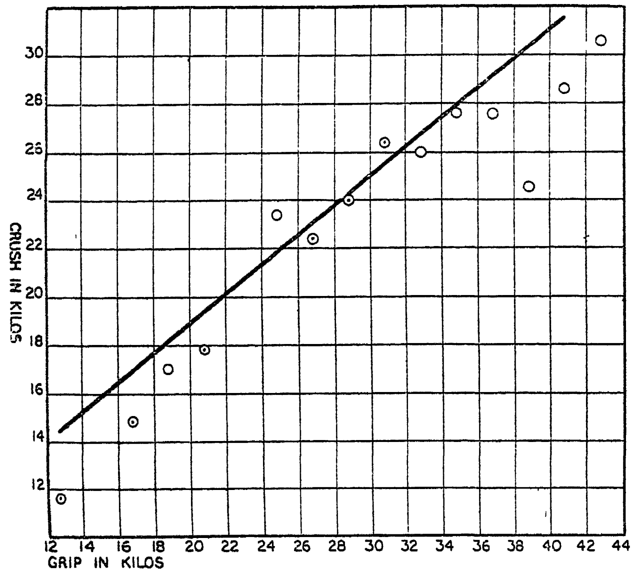

FIG. VI. Factory Women aged 21 years, regression line and observations. Crush on Grip

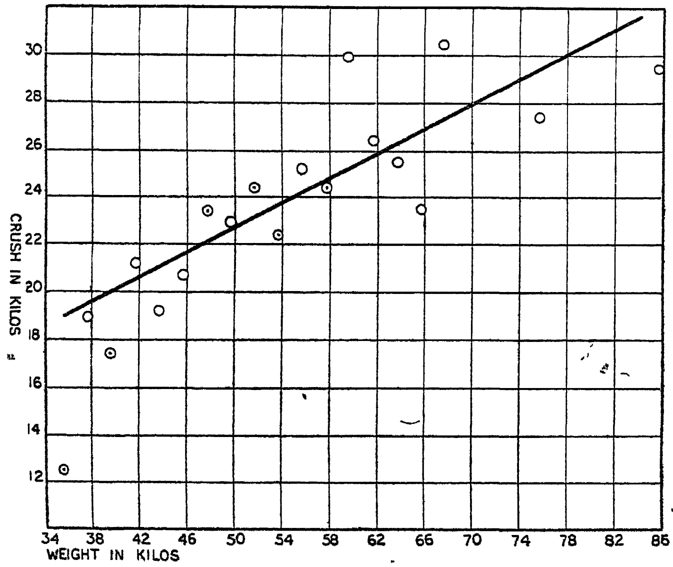

FIG. VII. Factory Women aged 23 years, regression line and observations. Crush on Weight.

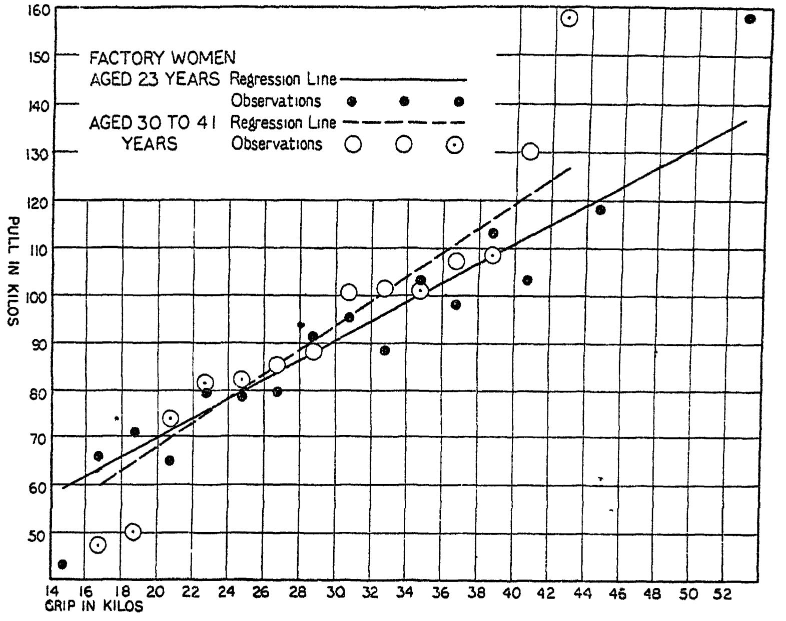

FIG. VIII. Factory Women, regression line and observations. Pull on Grip.

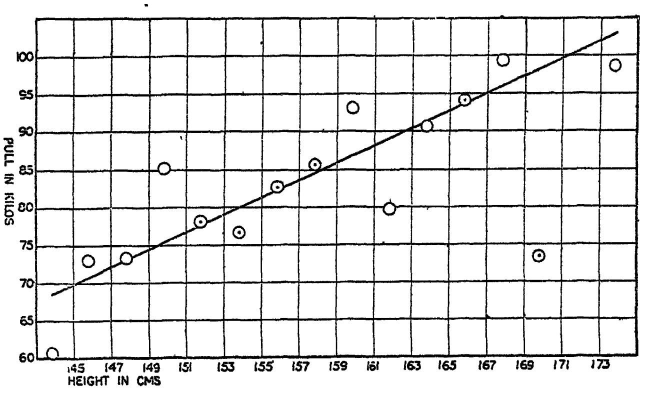

FIG. IX. Factory Women aged 23 years, regression line and observations. Pull on Height.

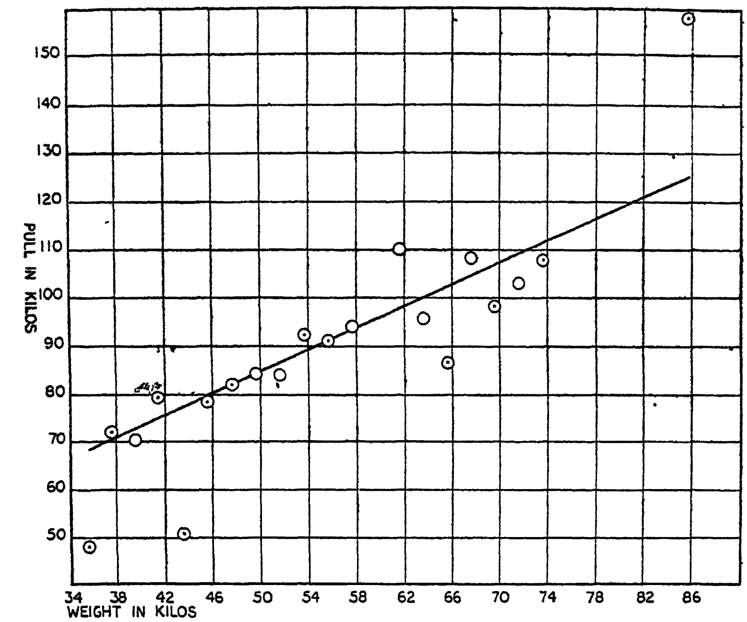

FIG. X. Factory Women aged 23 years, regression line and observations, Pull on Weight.

Tables XVII, XVIII and XIX give the averages of the weights, heights and pulls of the factory women examined arranged according to industries. They are separated into three groups. Girls, 14–16 ; girls, 16–18 ; and women. These tables incidentally make it clear how the 3,076 women examined were distributed as to employment. Table XX has the women arranged in trades in their order of merit in the lumbar pull test. It shows quite definitely that either by a process of weeding out or of judicious selection or of development on the part of the subject, the heavy trades have undoubtedly the women with the best developed musculature. It will be noted that at the chemical and brick works the two heaviest industries investigated, the average pull is practically identical and some 15 kilos greater than the next in order, viz., women engaged in the pottery trades. Although for the rest of the trades examined the average pull varies from 91·7 kilos to 74·1 kilos, the change is very gradual. It is difficult if not impossible, to ascribe the relative positions to any particular cause though, speaking quite generally, the heavier the trade the greater the strength of the women employed. In view of the relatively casual method used in the selection of women, the only probable explanation is that it is a case of the survival of the fittest.

TABLE XVII.—*Averages of Weight, Height, and Pull in different Industries—Girls.* **14–16** *years.*

Industry, etc.	No.	Wt. (kilos)	Ht. (cm.)	Pull (kilos)
Printing—Glasgow	4	47·38	157·2	61·8
Engineering and Metal Working—				
Glasgow (Bolts)	3	44·09	152·0	75·3
Midlands (Bolts)	3	51·06	155·6	72·3
Midlands (Chains)	8	46·08	157·1	69·4
Midlands (Hollow-ware) . ..	12	46·14	159·6	81·6
Midlands (Pens)	4	40·34	158·7	78·4
Midlands (Telephone). . ..	2	43·86	154·2	85·0
Textile—				
Glasgow (Carpets) . . .	24	45·23	156·2	73·6
Lancs. (Cottons (1)) . .	3	46·36	152·7	74·8
Lancs. (Cottons) (2)	21	38·57	149·6	58·6
Warehouse—				
Glasgow (1)	2	46·14	162·8	70·5
Glasgow (2)	3	55·45	161·3	87·5
Bakery—Glasgow	28	46·92	154·7	69·8
Clothing—Glasgow.. . ..	14	39·64	150·3	73·6
Chemical—Glasgow	—	—	—	—
Laundry—				
Glasgow	13	42·79	149·7	66·8
London	13	38·35	150·1	64·8
Shoes—Midlands	47	43·96	157·7	73·6
Pottery—				
Midlands (1)	14	42·79	154·4	77·5
Midlands (2)	9	44·24	154·5	81·8
Bricks—Midlands	—	—	—	—
Confectionery—				
Glasgow (Sweets)	8	43·64	153·1	67·8
London (Tea and Sweets) . .	12	46·51	158·5	80·3
London (Jam)	2	54·55	160·8	92·3
Soap—London	11	43·64	157·8	70·2
Bottling—London	33	46·61	158·6	81·4

TABLE XVIII.—*Averages of Weight, Height, and Pull in different Industries—Girls.* **16–18** *years.*

Industry, etc.	No.	Wt. (kilos)	Ht. (cm)	Pull (kilos)
Printing—Glasgow	11	49·21	157·0	74·2
Engineering and Metal Working—				
Glasgow (Bolts)	24	48·35	153·6	78·7
Midlands (Bolts)	23	51·04	160·5	84·9
Midlands (Chains)	22	49·92	158·8	81·1
Midlands (Hollow-ware)	30	48·50	158·1	81·4
Midlands (Pens)	2	46·60	158·9	83·8
Midlands (Telephone)..	9	53·43	162·3	78·3

TABLE XVIII.—*Averages of Weight, Height, and Pull in different Industries—Girls.* **16–18** *years.*—contd.

Industry, etc.	No.	Wt. (kilos)	Ht. (cm.)	Pull (kilos)
Textile—				
Glasgow (Carpets)	47	51·07	158·4	85·1
Lancs. (Cotton) (1)	11	45·91	156·4	84·3
Lancs. (Cotton) (2)	26	45·72	157·2	71·1
Warehouse—				
Glasgow (1)	8	51·36	162·1	85·5
Glasgow (2)	8	51·08	162·7	74·2
Bakery—Glasgow	40	52·06	157·2	76·4
Clothing—Glasgow..	19	46·63	152·0	75·0
Chemical—Glasgow	1	49·09	149·4	102·0
Laundry—				
Glasgow	18	43·10	154·1	78·1
London	3	43·94	154·0	69·0
Shoes—Midlands	55	46·32	156·6	78·2
Pottery—				
Midlands (1)	28	44.30	153·9	87.8
Midlands (2)	15	46·17	156·2	83·4
Bricks—Midlands	1	50·91	157·8	102·5
Confectionery—				
Glasgow (Sweets)	6	47·20	150·8	87·9
London (Tea and Sweets) . ..	32	47·89	159·5	82·2
London (Jam)	18	49·72	159·1	88·8
Soap—London	30	45·10	158·1	72·9
Bottling—London	10	45·86	157·9	85·8

TABLE XIX.—*Averages of Weight, Height, and Pull in different Trades—Women.*

Industry, etc.	No.	Wt. (kilos)	Ht. (cm.)	Pull (kilos)
Printing—Glasgow	23	52·96	157·9	79·5
Engineering and Metal Working—				
Glasgow (Bolts)	102	52·10	153·3	86·4
Midlands (Bolts)	152	50·37	158·9	83·5
Midlands (Chains)	90	50·37	158·6	80·6
Midlands (Hollow-ware)	113	50·94	158·3	89·5
Midlands (Pens)	40	51·11	156·1	79·1
Midlands (Telephone)..	118	52·56	158·9	84·0
Textile—				
Glasgow (Carpets)	153	52·01	157·7	89·3
Lancs (Cotton) (1)	139	49·82	155·2	76·6
Lancs. (Cotton) (2)	104	48·12	156·9	79·4
Warehouse—				
Glasgow (1)	48	51·05	158·9	85·6
Glasgow (2)	48	52·28	161·1	85·0
Bakery—Glasgow	182	51·95	156·6	80·2
Clothing—Glasgow..	70	51·02	157·5	81·4
Chemical—Glasgow	38	48·28	150·8	106·8

TABLE XIX.—*Averages of Weight, Height, and Pull in different Trades—Women.*—contd.

Industry, etc.	No.	Wt. (kilos)	Ht. (cm.)	Pull (kilos)
Laundry—				
Glasgow	28	49·11	156·4	82·8
London	20	52·39	151·3	74·1
Shoes—Midlands	138	48·84	158·0	82·2
Pottery—				
Midlands (1)	75	49·64	155·5	91·1
Midlands (2)	77	51·33	157·4	91·7
Bricks—Midlands	60	53·11	157·4	106·1
Confectionery—				
Glasgow (Sweets)	17	48·96	153·0	82·9
London (Tea and Sweets)	156	48·98	157·9	85·4
London (Jam)	98	53·18	159·7	89·5
Soap—London	140	48·30	159·5	79·3
Bottling—London	75	49·24	157·8	90·8

TABLE XX.—*Average Pull arranged in order of magnitude—Women.*

Industry.	No.	Average Pull.
		kilos.
Chemical	38	106·8
Bricks	60	106·1
Pottery (2)	77	91·7
Pottery (1)	75	91·1
Bottling	75	90·8
Jam	98	89·5
Hollow-ware	113	89·5
Carpets	153	89·3
Engineering (Glasgow)	102	86·4
Warehouse (1)	48	85·6
Tea	156	85·4
Warehouse (2)	48	85·0
Telephone	118	84·0
Engineering (Midland)	152	83·5
Sweets	17	82·9
Laundry (Glasgow)	28	82·8
Shoes	138	82·2
Clothing	70	81·4
Chains	90	80·6
Bakery	182	80·2
Printing	23	79·5
Cotton (1)	104	79·4
Soap	140	79·3
Pens	40	79·1
Cotton (2)	139	76·6
Laundry (London)	20	74·1

TABLE XXI.

Industry.	K.Wt. / cm. Ht.	cm. Ht. / K. Wt.	K.Pull / K.Wt.
Printing	0·335	2·981	1·501
Engineering and Metal Working—			
Glasgow (Bolts)	0 340	2·942	1·658
Midland (Bolts)	0·317	3·155	1·658
Midland (Chains)	0·318	3·149	1·600
Midland (Hollow-ware)	0·322	3·108	1·757
Midland (Pens)	0·327	3·054	1·548
Midland (Telephone)	0·331	3·023	1·598
Textile—			
Glasgow (Carpets)	0·330	3·032	1·717
Lancs. (Cotton) (1)	0·321	3·115	1·538
Lancs. (Cotton) (2)	0·307	3·261	1·650
Warehouse—			
Glasgow (1)	0·321	3·113	1·677
Glasgow (2)	0 325	3 081	1·626
Bakery—Glasgow	0·332	3·014	1·544
Clothing—Glasgow	0 325	3·076	1·590
Chemical—Glasgow	0 320	3·123	2·212
Laundry—			
Glasgow	0·314	3·185	1·686
London	0·346	2·888	1·414
Shoes—Midland	0·309	3·235	1·683
Pottery—			
Midland (1)	0·319	3·133	1·835
Midland (2)	0·326	3·066	1·786
Bricks—Midland	0·337	2·964	1 997
Confectionery—			
Glasgow (Sweets)	0 320	3·125	1·693
London (Tea and Sweets)	0·310	3·224	1·744
London (Jam)	0·333	3·003	1·683
Soap—London	0·303	3·224	1·744
Bottling—London	0·312	3·205	1·844

In Table XXI we attempted to determine by a series of factors, using the average values, some standard characteristic which might give a positive clue to the physical essentials for a woman engaged in work. Pull divided by body weight certainly places the women of the heavy trades in the premier position. Apart from this we have been unable to detect or determine any constant.

After all the determinations of the data in age groups had been completed as already mentioned and in order to get readily manageable groups for preliminary treatment, particularly with regard to age, all cards were thoroughly shuffled and four random samples each of 200 were drawn. The results of this sampling are given in Tables XXII, XXIII and XXIV.

TABLE XXII.—*Factory Women. Random Samples.*

Random Sample.	No. in Sample.	Age (yrs.).			Weight (kilos).			Height (cms.).			Finger Tip Distance (cms.).		
		Mean.	S D	C. of V.	Mean.	S.D	C of V	Mean.	S D.	C. of V.	Mean.	S.D.	C. of V.
I	200	21·61 ±·28	5·93 ±·20	27·44 ±·99	49·82 ±·32	6 77 ±·23	13·60 ±·46	157·60 ±·29	6·04 ±·20	3·83 ±·14	59·56 ±·17	3·49 ±·12	5·85 ±·20
II	200	22·96 ±·31	6·57 ±·22	28·63 ±1·04	49·22 ±·35	7·25 ±·24	14·72 ±·50	157·33 ±·28	5·94 ±·20	3·77 ±·14	59·51 ±·17	3·46 ±·12	5·81 ±·20
III	200	21·92 ±·33	6·88 ±·23	31·40 ±1·16	50·42 ±·39	8·15 ±·27	16·16 ±·55	157·44 ±·29	5·99 ±·20	3 80 ±·14	59·50 ±·17	3·57 ±·12	5·99 ±·20
IV	200	22·63 ±·33	6·89 ±·23	30·45 ±1·12	50·35 ±·37	7·77 ±·26	15·43 ±·54	156·95 ±·29	6·02 ±·20	3·83 ±·14	59·20 ±·16	3·33 ±·11	5·62 ±·19

Random Sample.	No. in Sample.	Pull (kilos).			Grip (kilos).			Crush (kilos).		
		Mean	S D.	C of V.	Mean.	S.D	C. of V.	Mean	S D.	C. of V.
I	200	82·65 ±·78	16·27 ±·55	19·68 ±·68	26·50 ±·23	4·82 ±·16	18·18 ±·63	23·04 ±·30	6·39 ±·22	27·75 ±1·02
II	200	83·95 ±·92	19·25 ±·65	22·93 ±·82	26·53 ±·24	5·00 ±·17	18·85 ±·66	22·80 ±·35	7·36 ±·25	32·27 ±1·21
III	200	83·43 ±·76	15·97 ±·54	19·14 ±·66	26·36 ±·22	4·64 ±·16	17·60 ±·61	22·44 ±·32	6·67 ±·22	29·72 ±1·08
IV	200	81·70 ±·87	18·21 ±·61	22·29 ±·80	26·68 ±·23	4·76 ±·16	17·83 ±·63	22·48 ±·31	6·59 ±·22	29·30 ±1·08

It will be noted from Table XXII that the deviation from the average in any one of the samples is not great. From these values it may be deduced, taking into consideration the size of our total sample (3,076), that the average woman in industry weighs about 50 kilos or 110 lb., her height is about 157 cm. or 61·84 in., her average pull about 83 kilos or 183 lb., her grip 26·5 kilos or 58 lb. and her crush about 23·1 kilos or 50 lb. The mean values as determined from all the women examined were weight 49·67 as against 49·95 random sample; height, 157·32 to 157·33; pull, 83·18 to 82·93; grip, 26·44 to 26·52; and crush, 22·60 to 22·69. See Table XXXIII A.

As her finger tips are, on the average of the 800 random drawn cards, approximately 59·5 cm. or 23·43 inches from the ground, using Pearson and Lee's average measurement of 16·5 inches for the length of the forearm, it follows that the elbow height of the average woman in industry is approximately 39·9 inches.

This figure agrees well with the American figure of about 40 inches and that of Legros and Weston [19] for 200 girls in this country of 39·5 inches. As the working place for comfort should be below the elbow height—the arm inclined downwards at an angle of 15 to 20 degrees, i.e., a drop of the fingers from elbow level of about 4 inches, is comfortable—it follows that the theoretical height of the working bench for the average woman should be about 36 inches high. But as the majority of workers use shoes with heels varying between one and one and a half inches high this additional elevation must be allowed for so that the actual bench height should be one of about 37 inches.

It is interesting to compare these results with those which were given by Pearson [4] from his own and Galton's data. He found as regards stature that the average of his 1,000 women (adults under 65) was 159·9 cm. as compared with our random sample value (800) of 157·33 cm. In his much more limited data as regards body weight, 276 women between the ages of 23 and 36, he found a mean value of 55·34 kilos as against our 49·95 kilos. He also gave the values obtained by Galton who found a mean stature of 63·3 inches (160·72 cm.) for 770 women between the ages of 23 and 51. As regards the strength tests Galton's 276 women between the ages of 23 and 26 had a squeeze (strongest hand) of 52 lb. to our women's 58 lb. He calculated the average lumbar pull for women from Quetelet's data at 75·74 to our 82·93 kilos. His more limited data from Cambridge women students between 19 to 30 years may also be referred to here although it might be more appropriate to consider it when dealing with our Provincial College women. The following short table shows the differences from our factory women :—

	Mean Values for		
	Height. *in.*	*Weight.* *lb.*	*Squeeze.* *lb.*
Women Students (Camb.) ..	63·8	126·59	56·29
Do. (Glasgow Provincial College)	63·4	116·62	62·63
Factory Women	61·98	109·27	58·16

Benėdict and Harris [5] found a mean height for their 193 women of 161·96 cm., and a mean weight (without clothes) of 56·48 kilos. They give a very interesting table of height; the part with the addition of data from Greenwood, Thompson and Woods [20] relating to women may be cited :—

	Women Stature.		
	Mean. *cm.*	*S.D.*	*C. of V.*
Cambridge Students (Pearson) ..	162·26	6·00	3·70
Pearson's 2nd generations	162·23	6·63	4·07
,, family records	159·90	6·44	4·03
,, parental generations ..	158·70	6·07	3·83
New South Wales Criminals .	158·09	6·15	3·89
Nutrition Lab. data	161·96	5·19	3·20
Present data	157·33	6·00	3·81
Asylum population (2,732 women)	155·56	—	—

It will be noted that whilst the average height is somewhat low, the standard deviation and coefficient of variation of our large sample is practically identical with those previously obtained. Dr. Lucy Cripps [6] in her report found a mean height of 164·54 cm. for her Polytechnic Students, 159·92 cm. for her female Civil Servants and 163·63 cm. for her Bedford College women. As regards weight she had 56·42 kilos for the Polytechnic students and 53·18 kilos and 53·41 kilos for the Civil Servants and Bedford College women respectively.

TABLE XXIII.—*Factory Women. Random Samples.—Correlation Coefficients.*

Variables.	Sample.			
	I.	II.	III.	IV.
Age and Weight	+·314±·043	+·009±·048	+·204±·046	+·163±·046
Age and Height	+·013±·048	—·137±·047	—·123±·047	+·026±·048
Age and Pull .	—·094±·047	+·102±·047	+·006±·048	—·101±·047
Age and Grip .	+·111±·047	+·189±·046	+·010±·048	—·036±·048
Age and Crush ..	+·062±·048	—·035±·048	—·006±·048	—·061±·048
Weight and Height	+·445±·038	+·579±·032	+·426±·039	+·523±·035
Weight and Pull	+·276±·044	+·330±·043	+·344±·042	+·266±·044
Weight and Grip	+·332±·042	+·389±·041	+·319±·043	+·388±·041
Weight and Crush	+·326±·043	+·332±·042	+·270±·044	+·243±·045
Height and Finger Tip Distance	+·791±·018	+·793±·018	+·774±·019	+·805±·017
Height and Pull	+·305± 043	+·367±·041	+·239±·045	+·294±·044
Height and Grip	+·416±·039	+·461±·038	+·230±·045	+·416±·039
Height and Crush	+·425±·039	+·404±·040	+·263±·044	+·346±·042
Pull and Grip ..	+·558± 033	+·665±·027	+·605±·030	+·595±·031
Pull and Crush ..	+·492±·036	+·587±·031	+·476±·037	+·532±·034
Grip and Crush ..	+·364±·041	+ 593±·031	+·482±·037	+·443±·038

TABLE XXIV.—*Factory Women. Random Samples.—Correlation Ratios.*

Variables.	Sample.			
	I.	II.	III.	IV.
Weight on Age ..	·360 ± ·042	·230 ± ·043	·227 ± ·045	·355 ± ·042
Height on Age ..	·292 ± ·044	·186 ± ·046	Indeterminate	·165 ± ·046
Pull on Age ..	·191 ± ·046	·178 ± ·046	·217 ± ·045	·279 ± ·044
Grip on Age ..	·156 ± ·047	Indeterminate	Indeterminate	·320 ± ·043
Crush on Age ..	·359 ± ·042	·216 ± ·046	Indeterminate	·341 ± ·042
Height on Weight	·577 ± ·032	·603 ± ·030	·418 ± ·039	·554 ± ·033
Pull on Weight ..	·411 ± 040	·360 ± ·042	·347 ± ·042	·244 ± ·045
Grip on Weight	·414 ± ·040	·325 ± ·043	·297 ± ·044	·366 ± ·041
Crush on Weight	·402 ± ·040	·303 ± ·043	·329 ± ·043	·248 ± ·045
Finger Tip Distance on Height.	·789 ± ·018	·798 ± ·017	·761 ± ·020	·817 ± ·016
Pull on Height ..	·326 ± ·043	·395 ± ·040	·239 ± ·045	·325 ± ·043
Grip on Height ..	·401 ± ·040	·441 ± ·038	·168 ± ·046	·438 ± ·039
Crush on Height	·468 ± ·037	·445 ± ·038	·236 ± ·045	·377 ± ·041
Grip on Pull ..	·552 ± ·033	·665 ± ·027	·602 ± ·030	570 ± ·032
Crush on Pull ..	·513 ± ·035	·571 ± ·032	·469 ± ·037	·523 ± ·035
Crush on Grip ..	·319 ± ·043	·606 ± ·030	·449 ± ·038	·442 ± ·038

Tables XXIII and XXIV give the correlation coefficients and the correlation ratios for a number of variables from these random samples. Speaking generally it may be said there is only a small correlation with age. There is marked inter-dependence between height and finger tip distance, weight and height, pull and grip, pull and crush and grip and crush. The data further show that there is perhaps on the whole a better correlation between height and the strength tests than between weight and these tests.

GROUP 2.—UNEMPLOYED WOMEN.

We now turn to the investigation of our group of 413 unemployed women who had, as already noted, spent several years in factory work but who had been out of work for one year and over. Our reason for including this group of women in our study was primarily to see whether, when a worker had been on the unemployed list for a year or more, she exhibited any definite signs of physical deterioration. It seemed to us that one of the ill effects arising out of prolonged unemployment might be a loss to some extent of muscular development due to the lack of continuous exercise. It may be remarked here that this deterioration would not be so likely to occur in women as in men for the simple reason that amongst the most strenuous of occupations an occupation which gives all muscles exercise, is the so-called simple round of household scrubbing, washing, etc.

TABLE XXV.—*Unemployed Women.*

Physical Measurements.

Age Group.	No. in Group.	Weight (kilos) Mean.	Weight S.D.	Weight C. of V.	Height (cm.) Mean.	Height S.D.	Height C. of V.	Finger Tip Distance (cm.) Mean.	Finger Tip S.D.	Finger Tip C. of V.
$19^6/_{12}$–$24^5/_{12}$	166	47·24 ±·34	6·50 ±·24	13·75 ±·51	151·28 ±·33	6·36 ± 24	4·20 ±·15	56·59 ±·20	3·90 ±·14	6·89 ±·26
$24^6/_{12}$–$34^5/_{12}$ . ..	174	49·60 ±·44	8·63 ±·31	17·40 ±·65	152·67 ±·38	7 34 ±·27	4·81 ±·18	57·59 ±·21	4·13 ±·15	7·16 ±·25
$34^6/_{12}$–$55^5/_{12}$	73	54·94 ±·91	11·48 ±·64	20·89 ±1·22	152·94 ±·51	6·48 ±·36	4·24 ±·22	58·51 ±·28	3·52 ±·20	6·01 ±·34

Strength Tests.

Age Group.	No. in Group.	Lumbar Pull (kilos). Mean.	Lumbar Pull S.D.	Lumbar Pull C. of V.	Hand Grip (kilos). Mean.	Hand Grip S.D.	Hand Grip C. of V	Crush (kilos) Mean.	Crush S.D.	Crush C of V.
$19^6/_{12}$–$24^5/_{12}$	166	75·36 ±·88	16·83 ±·62	22·33 ±·87	25·17 ±·25	4 79 ±·18	19·02 ±·73	19·91 ±·33	6·24 ±·23	31·33 ±1·28
$24^6/_{12}$–$34^5/_{12}$	174	75·41 ±·97	19·03 ±·69	25·24 ±·96	24·91 ± 26	5 17 ±·19	20·77 ±·77	19·46 ±·28	5 47 ±·20	28·12 ±1·09
$34^6/_{12}$–$55^5/_{12}$	73	73·59 ±1·30	16·50 ±·92	22·42 ±1·32	24·35 ±·37	4·69 ±·26	19·27 ±1·10	16·57 ±·33	4·22 ±·24	25·46 ±1·51

TABLE XXVI.—*Unemployed Women.*

Variables.	Correlation Coefficients. (r).			Correlation Ratios. (η)		
	$19^6/_{12}$–$24^5/_{12}$ years. (166)	$24^6/_{12}$–$34^5/_{12}$ years. (174)	$34^6/_{12}$–$55^5/_{12}$ years. (73)	$19^6/_{12}$–$24^5/_{12}$ years. (166)	$24^6/_{12}$–$34^5/_{12}$ years. (174)	$34^6/_{12}$–$55^5/_{12}$ years. (73)
Weight and Height ..	+·573±·035	+·500±·038	+·441±·064	+·598±·034	+·577±·034	+·381±·068
Weight and Pull ..	+·365±·045	+·343±·045	+·328±·070	+·349±·046	+·399±·043	Indeterminate
Weight and Grip ..	+·276±·048	+·313±·046	+·389±·067	+·240±·049	+·298±·047	+·245±·074
Weigth and Crush ..	+·353±·046	+·276±·047	+·266±·073	+·348±·046	+·176±·050	Indeterminate
Height and Finger Tip Distance	+·789±·020	+·850±·014	+·779±·031	+·784±·020	+·849±·014	+·743± 035
Height and Pull ..	+·387±·045	+·385±·044	+·258±·074	+·389±·044	+·349±·045	+·199±·076
Height and Grip ..	+·334±·047	+·360±·045	+·306±·072	+·342±·046	+ 315±·046	+·270±·073
Height and Crush ..	+·326±·047	+·397±·043	+·171±·077	+·401±·044	+·311±·046	Indeterminate
Pull and Grip.. ..	+·548±·037	+·567±·035	+·622±·048	+·521±·038	+·578±·034	+·626±·048
Pull and Crush ..	+·659±·030	+·511±·038	+·482±·061	+·643±·031	+·493±·039	+·490±·060
Grip and Crush ..	+·598±·034	+·557±·035	+·479±·061	+·589±·034	+·610±·032	+·468±·062

Table XXV gives the data of our unemployed arranged in three age groups. Incidentally it may be remarked that in practice it was found rather difficult to obtain a sufficiently large number of women who were unemployed for a year or more and who had been engaged in factory work.

Our data shows that with advancing years there is a definite increase in body weight, that the height is as would be anticipated practically constant although curiously enough there would seem to be a definite increase of finger tip distance from the ground. As regards the strength tests with lumbar pull the capacity would seem to be equal for the first two age groups with a definite decline in the last. The decline is also well-marked with the crush test and is evident although small with the hand grip. A comparison of these data with the factory women engaged in active work will be made later (see page 61).

The correlation values are given in Table XXVI. They show a marked interdependence between weight and height, height and finger tip distance, and between the various strength tests. Correlation is also quite good between weight and pull, height and pull and the strength tests. With the exception of weight and grip the correlations in the last age group are lower than in the other two. Admittedly the numbers are fewer in the last group, but the relative poorness of the correlation is probably rather to be associated with the variation in age of the members of this group than with the smallness of number.

A single random sample of 200 cards, approximately half of the total number of women examined, was selected by a disinterested person. The results of the statistical treatment of this sample will be found in Table XXVII. The mean value of the physical measurements indicates an average height of approximately 152 cm. or 59·78 inches with a weight of approximately 50 kilos or 110 lb. The average pull is about 75 kilos of 165 lb., grip 25 kilos or 55 lb. and crush 19 kilos or 42 lb. Table XXII shows that the average of the random sample of factory women actively employed was approximately—height, 157 cm.; weight, 50 kilos; pull, 83, grip, 26·5; and crush, 23 kilos. Thus from the comparison of these two random samples it would seem that the unemployed women were of equal weight but of less height, therefore smaller and stouter than their employed sisters and that they were on the whole less muscular as proved by these tests (see also Table XXXIIIA which gives total values). One, of course, must be very cautious in drawing deductions from strength tests as they are indicative not only of muscle but of mental alertness or will power As Martin (*v.s.*) has pointed out, in woman "the most striking feature with regard to her strength is its correlation with mental alertness rather than with muscular development." These data raise then the general question as to whether the long duration of unemployment of the women in question may not be in part due to the fact that their physical and psychical make up do not

appeal to those employing labour. Some force is given to this hypothesis by the fact that in the employment exchanges where these women were obtained those with several years unemployment were on the average amongst the older women Apart from these the unemployment seemed to be transitory since in one of the exchanges 2,000 women were on its lists but only about 140 of these had been out of work for over a year

TABLE XXVII.—*Unemployed. Random Sample of* 200 *cards.*

Factor.	Mean.	S.D.	C. of V.
Age (years)	29·31 ±·426	8·93 ±·301	30·46 ±1·120
Weight (kilos)	49·69 ± 446	9·35 ±·315	18·81 ±·663
Height (cm.)	151·80 ±·337	7·07 ±·238	4·66 ±·152
Finger Tip Distance (cms.)	57·22 ±·195	4·08 ±·138	7·12 ±·237
Pull (kilos)	75·18 ±·863	18·09 ±·610	24·07 ±·855
Grip (kilos)	24·96 ±·235	4·92 ±·166	19·72 ±·682
Crush (kilos)	19·03 ±·273	5·72 ±·193	30·04 ±1·099

Correlation Coefficients.		Correlation Ratios.	
Variables.		Variables.	
Age and Weight	+·236±·045	Weight on Age	+·409±·040
Age and Height	+·070±·048	Height on Age	Indeterminate
Age and Pull	—·070±·048	Pull on Age	+·134±·047
Age and Grip	—·060±·048	Grip on Age	+·166±·046
Age and Crush	—·161±·047	Crush on Age	+·177±·046
Weight and Height	+·507±·035	Height on Weight	+·620±·030
Weight and Pull	+·330±·043	Pull on Weight	+·299±·043
Weight and Grip	+·340±·042	Grip on Weight	+·288±·044
Weight and Crush	+·230± 045	Crush on Weight	+·042±·048
Height and Finger Tip Distance.	+·843±·014	Finger Tip Distance on Height.	+·841±·014
Height and Pull	+·425±·039	Pull on Height	+·423±·039
Height and Grip	+·461±·038	Grip on Height	+·482±·037
Height and Crush	+·383±·041	Crush on Height	+·401±·040
Pull and Grip	+·612±·030	Grip on Pull	+·631±·029
Pull and Crush	+·583±·032	Crush on Pull	+·566±·032
Grip and Crush	+·533±·034	Crush on Grip	+·542±·034

There was a further difference between the employed and the unemployed women. One of the questions those investigated were asked was whether they took any systematic exercise.

In the more modern factories there were numerous organised games, drill and gymnastics and other opportunities for regular exercise. Not all the girls availed themselves of these opportunities, some of them said that they were too tired by the end of the day and others had a long journey home. Nearly all the girls said that they did a good deal of walking but one must remember that this so-called walking, though undoubtedly exercise, is not strenuous. It usually implies, apart from the walk to and from the factory which may be of very varying distance, a saunter through the streets after working hours In this connection it must not be forgotten that most of the married women and very many of the single women had all the work of the house to do besides their factory work. On enquiry we found that none of the unemployed women examined played games or took exercise in any more strenuous form than walking.

As regards the correlations it will be noted that apart from age and weight there is no interdependence on age whereas the other correlations follow very closely the results obtained with the whole group as given in Table XXVI.

GROUP 3.—COLLEGE WOMEN.

We now turn to the consideration of our group 3 of 460 of the Provincial College women whom we selected as a particularly homogenous class of sedentary workers to act as a general control. As a body of women they were limited in age and they led daily lives of practically identical nature. They were all in training for the teaching profession. Table XXVIII gives the physical measurements arranged in four age groups, the first three being yearly, the fourth consisting of two years. It will be noted that there is a marked uniformity over all in weight, height and finger tip distance. There is also not much difference in the grip and crush strength tests, but there is more variation in the lumbar pull. No random sample of this collection of material was made as it was such a homogeneous group both in age and measurements.

The striking thing which the data disclose is the really excellent physical condition of this group of young women when compared with their sisters engaged in industry. They are taller, heavier and stronger than the bulk of the other women examined. To what is this superiority to be ascribed? In the first place a very large number of these girls, about 55 per cent, were born and brought up in country districts—they came from all parts of Scotland—being drawn from good sound stock but not from affluent families. They all undergo a very strict medical examination before they are permitted to enter the College and during the whole time they are students they are kept under strict medical supervision. Possibly, although this cannot be the sole explanation as those in the first age group (and out of the 460 examined there were only eight girls under 18 years of

TABLE XXVIII.—*Physical Measurements. Women Students (Jordanhill).*

Age Group.	No. in Group.	Weight (kilos).			Height (cm.).			Finger Tip Distance (cm.).		
		Mean.	S.D.	C. of V.	Mean.	S.D.	C. of V.	Mean.	S.D.	C of V.
$18^6/_{12}$–$19^5/_{12}$ ..	113	53·77 ±·51	8·11 ±·36	15·09 ±·69	161·50 ±·34	5·33 ±·24	3·30 ±·16	60·84 ±·21	3·25 ±·15	5·34 ±·25
$19^6/_{12}$–$20^5/_{12}$ ..	139	52·79 ±·42	7·30 ±·30	13·83 ±·58	160·74 ±·31	5·41 ±·22	3·37 ±·14	60·25 ±·18	3·10 ±·13	5·15 ±·20
$20^6/_{12}$–$21^5/_{12}$ ..	101	53·55 ±·46	6·92 ±·33	12·93 ±·63	160·86 ±·35	5·18 ±·25	3·22 ±·14	60·41 ±·22	3·34 ±·16	5·53 ±·26
$21^6/_{12}$–$23^5/_{12}$ ..	107	52·00 ±·47	7·27 ±·34	13·97 ±·66	160·81 ±·33	5·03 ±·23	3 13 ±·14	60·73 ±·20	3·12 ±·14	5·13 ±·23

Strength Tests.

Age Group.	No. in Group.	Lumbar Pull (kilos).			Hand Grip (kilos).			Crush (kilos).		
		Mean.	S.D.	C. of V.	Mean.	S D	C of V.	Mean.	S.D.	C. of V.
$18^6/_{12}$–$19^5/_{12}$ ..	113	96·57 ±·96	15·09 ±·68	15·63 ±·71	29·14 ±·36	5·60 ±·25	19·23 ±·88	26·40 ±·43	6·82 ±·31	25·85 ±1·24
$19^6/_{12}$–$20^5/_{12}$ ..	139	96·09 ±·93	16·26 ±·66	16·92 ±·71	27·61 ±·29	4·98 ±·20	18·05 ±·75	26·38 ±·42	7·31 ±·30	27·70 ±1·15
$20^6/_{12}$–$21^5/_{12}$ ..	101	98·99 ±1·00	14·90 ±·71	15·05 ±·73	28·70 ±·35	5·20 ±·25	18·11 ±·88	27·10 ±·44	6·52 ±·31	24·05 ±1·20
$21^6/_{12}$–$23^5/_{12}$ ..	107	100·63 ±1·00	15·27 ±·70	15·17 ±·71	28·67 ±·34	5·25 ±·24	18·30 ±·88	26·91 ±·45	6·85 ±·32	25·46 ±1·25

age) were as tall and heavy and practically as strong as their more senior colleagues, the fact that these girls all had two hours gymnastics per week and they all in addition played games such as hockey, tennis, badminton, etc , had a good deal to do with their superior strength development. At any rate this systematic physical training of girls drawn from good sound stock, associated with the general increase in mental alertness developed during their professional training, leads to the formation of a very good physique. Dr. Cripps, in the report already referred to [6], worked with two classes of students of about the same age, viz., those of the South Western Polytechnic Physical Training School (London) with an average age of 20·52 years and the Bedford College girls with an average age of 21·13 years She found a mean height of 164·54 cm for the Polytechnic students and 163·63 cm. for the Bedford College ones, and a mean weight of 56·42 kilos for the Polytechnic and 53·41 kilos for the Bedford College students. Both these values are higher than those of the present group. The figures for the Physical Training School girls are very striking and would suggest in view of the low standard deviations (4·02 for height and 5·42 for weight) and coefficient of variations (2·44 for height and 9·61 for weight) that this is a highly selected population. Again, it cannot be assumed that the girls attending this physical training school are drawn from the particularly well-to-do classes of the general population.

Mosher and Martin [12] in their much more limited study of 45 American College women, most of whom had always been physically active, although, in the majority of the instances, not specifically athletic, found that the average strength (utilising tests on 36 groups of muscles) of these college women was approximately 50 per cent. greater than the average of 116 women factory workers and this in spite of the fact that the factory workers were daily engaged in heavier manual work than any of the college women. Martin [13] also found that female clerks and other operatives whose tasks required mental alertness had regularly greater strength than operatives whose work was purely mechanical.

Martin [13] investigated the strength by his special test of 116 women engaged in engineering.

Table XXIX gives his results :—

TABLE XXIX.

Type of Work.	Operation.	No. of Women.	Average Strength. lb.	Average Weight. lb.
Definitely Laborious ..	Screw Machine	32	2,170	138
	Foot Press	12	2,020	126
	Drilling	24	1,860	126
Less Laborious	Fuse Assembly	9	1,860	125
	Dial Press	13	1,820	113
Manual Work, Light. Attention, Constant.	Clerks	8	2,180	113
	Lacquering	5	2,180	112
	Bench Work	13	1,910	120

No standard deviations are given for the above values but Martin states that " the standard deviation in the screw machine and drilling operations comes well within the limit demanded by a probability curve "

Viewing the above data it seems to us that the numbers measured are far too few to permit of any far reaching conclusions being drawn A further objection to the utilisation of these values for comparative purposes is, as Muscio [14] has shown, that the strength values obtained are influenced to a considerable extent by the technique and experience of the observer determining them.

Although many objections might be taken to the fewness of Martin's data and to the fallacies of his method we are of opinion that his conclusions are probably correct.

In this connection it is interesting to note the fact to which Martin draws attention that in men doing heavy routine manual labour there appears to be a definite adjustment of the strength to the demands made upon it, but that no such close relationship of strength to the physical demands of the occupation has been demonstrated for women. To explain these differences between the sexes Martin writes : " The suggestion is that in men the exhibition of strength is so familiar an accompaniment of daily life that they have the nervous mechanism for evoking it readily at command, whereas in women manifestations of strength are less matters of routine, so that general mental alertness plays a most important part."

This is a plausible suggestion and it may in part account for the high place these Provincial College women take in the strength tests.

TABLE XXX.—*Correlation Coefficients Women Students (Jordanhill).*

Variables.	Age.			
	19 years. (113)	20 years (139)	21 years. (101)	22 and 23 yrs. (107)
Weight and Height	+·538±·045	+ 617±·035	+·576±·045	+·532±·047
Weight and Pull	+·385±·054	+·404±·048	+·327±·060	+·442±·053
Weight and Grip	+·493±·048	+·414±·047	+·381±·057	+·382±·056
Weight and Crush	+·301±·058	+ 307±·052	+·163±·065	+·319±·059
Height and Finger Tip Distance.	+·734±·029	+·742±·026	+·739±·031	+·759± 028
Height and Pull	+·262±·059	+·338±·051	+·196±·065	+·338±·058
Height and Grip	+·317±·057	+·370±·049	+·337±·060	+·462±·051
Height and Crush	+·367±·055	+·369±·049	+·166±·065	+·324±·058
Pull and Grip ..	+·394±·054	+·545±·040	+·520±·049	+·516±·048
Pull and Crush ..	+·250±·060	+·492±·043	+·291±·061	+·490±·050
Grip and Crush ..	+·326±·057	+·409±·048	+·280±·062	+·464±·051

TABLE XXX A.—*Correlation Ratios. Women Students (Jordanhill).*

Variables	Age			
	19 years (113)	20 years (139)	21 years (101)	22 and 23 yrs (107)
Height, on Weight	+·486±·048	+·614±·036	+·633±·040	+·604±·041
Pull, on Weight .	+·384±·054	+·448±·046	+ 357±·059	+·461±·051
Grip, on Weight .	+·457±·050	+·362±·050	+ 408±·056	+·280±·060
Crush, on Weight	+·157±·062	+·311±·052	Indeterminate	+·384± 056
Finger Tip Distance, on Height.	+·742±·029	+·734±·026	+·762± 028	+·745±·029
Pull, on Height .	+·292± 058	+·270±·053	+·393± 057	+ 432±·053
Grip, on Height..	+·385±·054	+·295±·052	+·331±·060	+·460±·051
Crush, on Height	+·471±·049	+·397±·048	+·257±·063	+·433±·053
Grip, on Pull .	+·453±·050	+ 518±·042	+·554±·047	+·523±·047
Crush, on Pull ..	+·299±·058	+·437±·046	+·299±·061	+·497±·049
Crush, on Grip .	+·285±·058	+·424±·047	+·170±·065	+ 435±·053

As regards the correlations in this group which are given in Tables XXX and XXX A, it is evident again that there is very good interdependence between weight and height and height and finger tip distance in all age groups, and also a fairly high correlation between weight and the strength tests and between height and grip and crush but less good between height and pull. Curiously enough the correlations among the various strength tests are not so good as in the two previous groups. See also Figs. XI to XII which illustrate regression lines.

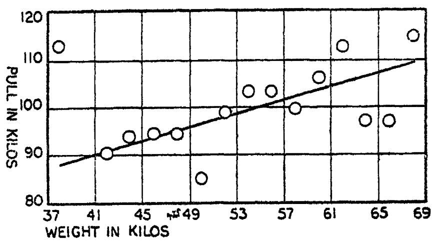

FIG. XI. College Women, regression line and observations. Pull on Weight

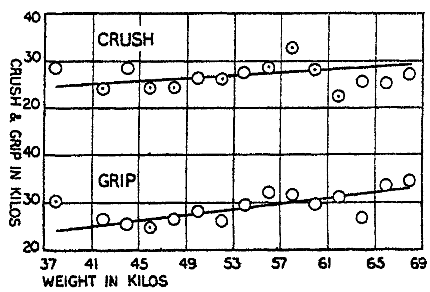

FIG. XII. College Women, regression lines and observations Crush and Grip in Weight.

Group 4.—Women Engaged in Heavy Trades.

This is our working out of the more limited data collected by Dr. Overton of the Home Office from a wide variety of women employed more or less in what may be referred to as the heavy trades (like the tin plate industry, engineering, pottery, etc.) Here no strength tests were made, but in place of this there is a very valuable collection of data on the actual load carried by the various workers examined under their normal conditions of activity. The data are given in three age groups. Taken as a group, as might be expected the majority being employed in heavy trades, they would seem to be slightly heavier than the factory women we examined, they are also slightly taller (see Table XXXI). Table XXXII gives the correlations. Again, as is to be expected, the correlation between weight and height is very good, except for some reason unknown, unless it be the increase in weight with age, in the third age group. In age groups 14–18 and 19–23 there would seem to be some correlation between body weight and load carried, and also, though less marked, between height and load carried. In each case in the third age group the correlation is less than in the first two. In this connection it must be remembered that although the workers may have some limited choice in the matter of the amount of material carried at any one time, there is more or less a standard amount which they are expected to lift or carry at a time. Hence, where the choice element exists at all, it is to be expected that as age advances and the physical powers or more probably the endurance diminishes there will be a tendency to more marked variation in the load dealt with. In this connection see Dr. Overton's report, Part III. In addition there is the fact that the weight of the body, an increase mainly in the form of fat, although not the muscularity, increases with advancing years. Still consideration of Table XXXI shows that the actual average load carried by the members of the third age group, although below that of the middle group, is above that of age group 14–18.

Table XXXI B gives an interesting distribution of the modes employed in handling the load. The majority utilise what may be termed three standard methods: (1) carrying the load in both hands utilising the abdominal wall or the pelvis as a support; (2) carrying the load on a board resting on the shoulder; (3) carrying the load under one arm and using the hip as a support; (4) other methods such as carrying the load on a tray slung from the shoulders, or in baskets carried in the hands, or in pans with handles or on head, a load is shared between two workers and so on. From the table it is evident that so far as the methods are concerned the bulk of the workers of all ages utilise method 1. Further, when the various methods are considered in terms of load carried, method 1 again takes first place. It is undoubtedly a convenient method both for picking up, setting down and carrying, but as Miss Bedale [1] showed in her report and as is again shown in the present report this method of carriage is by

TABLE XXXI.—*Women Employed in Heavy Trades.*

A.

Age group	No in Group	Weight (kilos)			Height (cm)			Load Carried (kilos)			Duration of Employment (years).			Load carried forms per cent. of body weight.
		Mean	S D.	C of V	Mean.	S D	C of V	Mean.	S D	C of V.	Mean	S D.	C of V.	
F.Y P 14–18 11/12	180	47·83 ±·42	8·35 ± 30	17 46 ±·64	156·12 ±·34	6 83 ±·24	4·38 ±·16	20·35 ±·49	9·67 ±·34	47·52 ±2·03	—	—	—	42·5
Women 19–23 11/12	120	52·83 ±·49	7·92 ±·34	14·99 ±·68	159 28 ±·43	6·93 ±·30	4·35 ±·20	23·20 ±·65	10·53 ±·46	45·39 ±2·36	4·23 ± 15	2·47 ± 11	58·43 ±3 30	43·9
Women 24–49 11/12	117	53·56 ±·52	8 36 ±·39	15 62 ±·70	158 95 ± 40	6·37 ±·29	4 01 ± 18	22·64 ±·63	10 09 ±·47	44 58 ±2 32	8·72 ± 54	6 27 ±·29	71·88 ±4·73	42 3

Average Load carried by different Methods (kilos).

B.

Age Group	No in Group	Method I.			Method II			Method III			Method IV			Methods of carrying
		Mean.	S D	C of V	Mean	S D	C of V	Mean	S D	C of V	Mean.	S D	C. of V.	
F Y.P. 14–18 11/12	180 *(178)	(109 in group) 21 61	11·59	53 65	(10 in group) 17 63	9 76	55 35	(1 in group) 11·58	—	—	(58 in group) 18 91	4·57	24 18	I In both hands, load supported against abdomen or pelvis. II On board over shoulder
Women 19–23 11/12	120	(78 in group) 24·81	11·97	48·23	(16 in group) 17·84	3·11	17·42	—	—	—	(26 in group) 22 51	6·86	30·46	III. Under one arm supported on hip
Women 24–49 11/12	117	(82 in group) 23 86	11·33	47 47	(14 in group) 18·60	4 90	26·34	—	—	—	(21 in group) 21·22	5 19	24·44	IV Other methods

* Method of load carrying not given in two cards.

TABLE XXXII.—*Heavy Trades.*

	Correlation Coefficients.			*Correlation Ratios.*		
Variables	F.Y.P 14–18. (180)	Women, 19–23. (120)	Women, 24–49. (117)	F.Y P 14–18	Women, 19–23	Women 24–49
Weight and Height	$+\cdot639\pm\cdot030$	$+\cdot616\pm\cdot038$	$+\cdot392\pm\cdot053$	$\cdot649\pm\cdot029$	$\cdot591\pm\cdot040$	$464\pm\cdot049$
Weight and Load	$+\cdot300\pm\cdot046$	$+\cdot275\pm\cdot057$	$+\cdot121\pm\cdot061$	$\cdot276\pm\cdot046$	$\cdot260\pm\cdot057$	$\cdot135\pm\cdot061$
Weight and Years employed	—	$-\cdot030\pm\cdot062$	$-\cdot008\pm 062$	—	$\cdot072\pm\cdot061$	$\cdot091\pm\cdot062$
Height and Load	$+\cdot264\pm\cdot047$	$+\cdot184\pm\cdot060$	$+\cdot034\pm\cdot062$	$\cdot076\pm\cdot050$	$\cdot239\pm\cdot058$	$\cdot155\pm\cdot061$
Height and Years employed	—	$-\cdot066\pm\cdot061$	$-\cdot181\pm\cdot060$	—	$\cdot093\pm\cdot061$	$\cdot251\pm\cdot058$
Load and Years employed	—	$+\cdot043\pm\cdot062$	$+\cdot126\pm\cdot061$	—	$\cdot346\pm\cdot054$	$\cdot163\pm\cdot061$

no means physiologically economical. Also it will be noted from the coefficient of variation that the amount carried at any one time may in each class vary within very wide limits. It must of course be remembered in reference to the loads carried that the determination is that of a single observation. Miss Overton was asked simply to make these chance observations in the course of her usual duties so that some real information of the loads actually carried in the course of an ordinary day's work might be obtained.

General Discussion.

Comparison Between Groups

We shall now turn to the consideration, not of the individual groups, but of their comparison with one another. As the two outstanding groups of our whole investigation were Group 1 (factory women employed) and Group 3 (College women) it may be best to begin with these two. As the numerical data may be obtained from some of the earlier tables in this report the actual comparison is now put forward in graph form, Figs XIII and XIV utilising, in order to make the comparison perfectly fair, the age groups of the factory women which agree with the age groups of the college women. It is obvious from

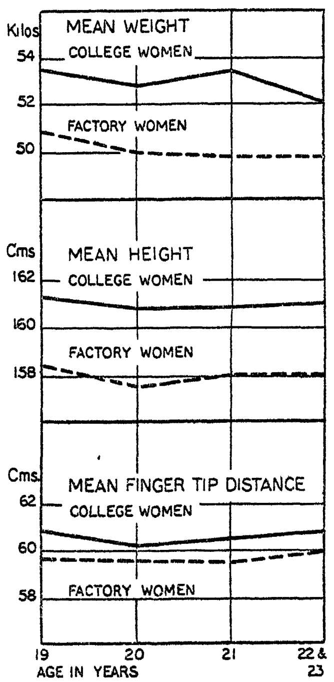

Fig XIII. Factory Women and College Women, comparison of physical measurements for different Age Groups

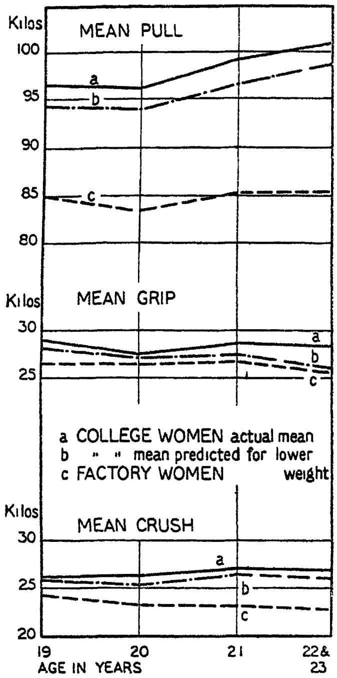

FIG. XIV. Factory Women and College Women, comparison of Pull, Grip and Crush for different Age Groups

even a mere casual glance at the graphs that in every respect—height, weight, pull, grip and crush—Group 3 is well in advance of Group 1 and further that the type of curve in both groups is practically identical. If, however, we compare the college women with the group of chemical workers, noting that the number of workers available in each of the age groups is very small, viz. 3, 2, 4 and 5 respectively, the mean pull of the chemical workers, except in age group 19, exceeds that of the college women.

	Mean Pull in Kilos	
Age Group.	*College Women*	*Chemical Workers.*
19	96·6	93·8
20	96·1	115·3
21	99·0	113·3
22 and 23	100·6	119·8

It might be argued that the smaller strength of the factory women was due to their smaller weight, since these two factors are correlated. In order to test this we utilised the regression lines of pull on weight and grip and crush on weight in the

college women (See Figs. XI and XII, p. 54). From these one can predict the mean pull, grip and crush for a smaller weight than was actually found in this group. That is one can make the weights of factory and college women comparable. The predicted means of strength are shown in Fig. XIV where it will be seen, that in spite of the reduction of the college women's body weights to those of the factory women, the predicted pull and crush still remain definitely higher, being reduced in both cases by about 29 per cent., whereas in the case of the grip the reduction is very definite and the superiority almost disappears at the last age groups

We now turn to a comparison of the average weight, height and pull of the college, factory and unemployed women which is recorded in Table XXXIII A, B and C. Incidentally the tables show the differences which actually exist between the averages of the totals and of the random samples in the groups of factory and unemployed women, and clearly demonstrate how closely the average of the random samples lies to the true average. This is perhaps not very noteworthy in the case of the unemployed where the random sample accounted for about 50 per cent. of the total, but it is an observation of value in the group of the factory women where the four random samples taken together formed only about 26 per cent. of the total. The result of our comparison is to show in actual figures that the average college woman is 3·75 cm. or about 1·5 inches taller than the average factory woman, who in turn is just over 5 cms. or about 2 inches taller than the average unemployed woman. As regards weight the college woman is about 3 kilos or 6·5 lb heavier than the factory woman, who is, however, almost equalled in weight by her unemployed sister. Finally, when pull is compared in terms of actual weight there is a difference of 14·8 kilos or 32·5 lb. in favour of the college woman as compared with the average factory woman, who in turn is some 8 kilos or 17·5 lb. better than the average of the unemployed women. At first sight the comparative data given in Table XXXIII A are most interesting and show definite differences existing between the various groups. The question immediately arises are these differences of real significance or merely a chance result. We worked out the significance, using the formula $0 \cdot 6745 \sqrt{\frac{\sigma^2}{n_1}+\frac{\sigma^2}{n_2}}$ where n_1 and n_2 were the number of units compared and σ the standard deviations of the respective series of measurements It is customary to maintain that any difference greater than three or more times the probable error is significant. As Table XXXIII B shows, in all cases, except weight between factory and unemployed women, the differences found are to be regarded as significant. In the majority of cases the difference found is many times greater than three times the probable error, and therefore we conclude the differences obtained can in no way be attributed to mere error in sampling.

TABLE XXXIII A.—*Comparison of Average Weight, Height and Strength in College, Factory, and Unemployed Women.*

	No.	Weight (kilos).			Height (cm).			Finger Tip Distance (cm).		
		Mean	S D.	C of V	Mean	S D.	C of V.	Mean	S D.	C. of V.
College Women.										
Total Average	460	53·01±0·23	7·45±0·16	14·06±0·32	160·97±0·17	5·26±0·12	3 27±0·07	60·54±0 10	3 20±0 07	5 29±0·12
Factory Women										
Four Random Samples	800	49·95±0 18	7·52±0·13	15·08±0·26	157·33±0·25	6·00±0·14	3·81±0 07	59 44±0 08	3·47±0 06	5 84±0 10
Total Average ..	3076	49·67±0·09	7·71±0·06	15·52±0·14	157 32±0 07	5·99±0·05	3 81±0 03	59 40±0 04	3·45±0 03	5 81±0 05
Unemployed										
Random Sample ..	200	49 69±0·45	9·35±0·32	18·82±0·65	151·80±0 34	7·07±0·24	4·66±0·15	57·22±0·19	4·08±0 14	7·12±0·24
Total average ..	413	49·60±0 29	8·88±0·21	17·90±0·43	152 16±0 23	6 85±0·16	4 50±0 11	57 35±0·13	3 99±0 09	6·96±0·17

	No.	Pull (kilos)			Grip (kilos)			Crush (kilos)		
		Mean	S D.	C of V	Mean	S D	C· of V	Mean	S D	C. of V
College Women										
Total average ..	460	97·90±0·49	15·56±0·35	15 90±0·36	28 47±0 17	5 28±0 12	18 55±0·43	26·66±0·22	6·92±0 15	25·96±0·62
Factory Women.										
Four Random Samples	800	82 93±0·42	17·50±0·30	21·10±0·37	26·52±0·11	4·81±0·08	18·14±0·31	22·69±0 16	6 77±0 11	29·84±0·55
Total average .	3076	83·18±0 21	17·60±0 08	21·16±0·09	26·44±0·06	4 94±0 02	18·67±0·08	22·60±0·08	6·55±0 03	28 98±0·27
Unemployed										
Random Sample	200	75·18±0·86	18·09±0·61	24·06±0·85	24·96±0·23	4 92±0·17	19·71±0·69	19·03±0·27	5·72±0·19	30·06±1 10
Total average	413	75·07±0·59	17·75±0·42	23·64±0 85	24·91±0·16	4 95±0 12	19 87±0·68	19·13±0·19	5·73±0·13	29·95±0 76

TABLE XXXIII B.—*Significance of Differences.*

	No	Weight.	Height	Pull.	Grip	Crush
College Total / Factory Total	460 / 3,076	3·34±0·25	3 65±0 18	14·72±0 53	2 03±0·18	4·06±0·23
College Total / Unemployed Total	460 / 413	3·41±0 12	8 81±0 29	22·83±0 34	3·56±0 23	7 53±0·29
Factory Total / Unemployed Total	3,076 / 413	0 07±0·30	5 16±0·23	8 11±0 63	1 53±0·17	3·47±0·21

TABLE XXXIII C —*Correlation Coefficients (r) in Total Groups.*

Variables.	Total Factory, 3,076.	Total Unemployed, 413.	Total College, 460.
Weight and Height	+·494±0 009	+·497±0·025	+·568±0·021
Weight and Pull ..	+·368±0·011	+·311±0·030	+·382±0·027
Weight and Grip .	+·395±0·010	+·279±0·031	+·422±0·026
Weight and Crush	+·304±0·011	+·204±0·032	+·277±0·029
Height and Finger Tip Distance.	+·778±0·005	+·816±0·011	+·742±0·014
Height and Pull .	+·308±0·011	+·362±0·029	+·285±0·029
Height and Grip .	+·468±0·010	+·331±0·030	+·371±0·027
Height and Crush .	+·387±0·010	+·311±0·030	+·315±0·028
Pull and Grip .	+·595±0·008	+·569±0·022	+·492±0·024
Pull and Crush .	+·532±0·009	+·560±0·023	+·396±0·027
Grip and Crush .	+·491±0·009	+ 558±0·023	+·372±0·027

PHYSICAL FITNESS

Is it possible from the data obtained to develop any general criterion or law from any or all of the measurements which will enable us to place the workers in categories of physical fitness? We have attempted many forms of calculation but so far without success. The following Table XXXIV gives the data of some of the calculations. Taking the group of the factory women employed and unemployed it is evident that by taking the two variables weight and pull representing nutrition (more or less) and muscularity, some sort of order which agrees with working conditions emerges. We obtain from pull/weight a figure of 1·692 as the average for employed factory women, all trades, for those engaged in heavy work 1·953, and those on sedentary 1·569, and for those unemployed it falls to 1·478. Again the college women stand out above the average of factory women but below those engaged in heavy trades.

TABLE XXXIV.

Women over 18 years of Age.	K Wt / cm Ht.	cm. Ht. / K. Wt.	K. Pull. / K Wt.
Factory Women. All Trades	0·323	3·095	1·692
Avs of ratios of 4 definitely *Heavy Trades*	0·323	3·100	1·953
Avs. of ratios of 2 definitely *Sedentary Trades*	0·326	3·065	1·569
Avs. of ratios of 5 Factories under definitely *Good Conditions*	0·321	3·117	1 663
Unemployed. All ages	0·332	3·010	1·478
College Women All ages	0·329	3 037	1·847
" Heavy Trades " (S.G.O.) Aged 19–49	0·334	2·991	—

TABLE XXXV.—*Factory Women.*

Age Group.	No.	Total Strength / Wt.	Total Strength / Ht
$14^0/_{12}$–$14^5/_{12}$	34	2·62	0 672
$14^6/_{12}$–$15^5/_{12}$	152	2·61	0·732
$15^6/_{12}$–$16^5/_{12}$	213	2·69	0·796
$16^6/_{12}$–$17^5/_{12}$	257	2·66	0·809
$17^6/_{12}$–$18^5/_{12}$	259	2·67	0·846
$18^6/_{12}$–$19^5/_{12}$	269	2·66	0·857
$19^6/_{12}$–$20^5/_{12}$	247	2·66	0·846
$20^6/_{12}$–$21^5/_{12}$	210	2·71	0·859
$21^6/_{12}$–$22^5/_{12}$ ..	211	2·72	0·854
$22^6/_{12}$–$23^5/_{12}$.	197	2·70	0 852
$23^6/_{12}$–$24^5/_{12}$	141	2·76	0·886
$24^6/_{12}$–$25^5/_{12}$	146	2·73	0·862
$25^6/_{12}$–$26^5/_{12}$ . .	124	2·72	0·875
$26^6/_{12}$–$28^5/_{12}$	164	2·66	0·864
$28^6/_{12}$–$30^5/_{12}$	116	2·61	0·837
$30^6/_{12}$–$40^5/_{12}$	232	2·60	0·875
$40^6/_{12}$–$55^5/_{12}$	104	2·34	0·807
Mean		2·66	
Random Samples			
Sample I	200	2·65	0·839
II	200	2·71	0·847
III	200	2·62	0·840
IV	200	2·60	0·834

TABLE XXXV.—*Factory Women*—contd.

Unemployed Women.

Age Group.	No.	Total Strength / Wt.	Total Strength / Ht
$19^6/_{12}$–$24^5/_{12}$	166	2·51	0·796
$24^6/_{12}$–$34^5/_{12}$	174	2·41	0·785
$34^6/_{12}$–$55^5/_{12}$	73	2·08	0·749
Random Sample	200	2·40	0·785
Mean		2·38	
College Women.			
$18^6/_{12}$–$19^5/_{12}$	113	2·82	0·942
$19^6/_{12}$–$20^5/_{12}$	139	2·84	0 934
$20^6/_{12}$–$21^5/_{12}$	101	2·89	0·962
$21^6/_{12}$–$23^5/_{12}$	107	3·02	0·971
Mean		2·88	

As pull alone gives an index of only one group of muscles, we utilised for the composition of Table XXXV all three strength tests and divided the sum of these values by weight. Table XXXV gives the values obtained for all the age groups of employed factory women and also of the random samples of this group, and of the age groups both of the college and unemployed women. In the employed factory women age groups it is interesting to note that the factor rises from the two earliest groups and would seem therefore to reach a level about 16. It remains then fairly constant, although the upward inclination continues to be evident until about age 24, until it rapidly falls away about

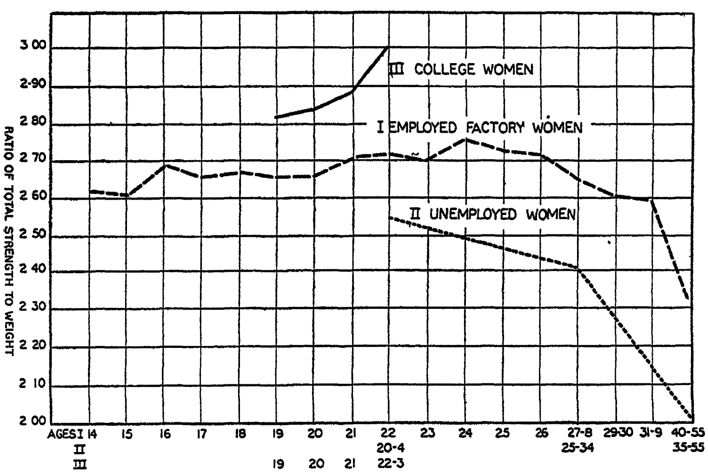

FIG. XV. Factory Women, Unemployed Women, and College Women, comparison of ratio of total strength to weight for different Age Groups.

the age of 39. The random samples reflect very fairly the average factor. In the college women groups, as was to be expected from the previous findings, the factor is definitely greater than that of the factory women. It would seem, although the number of age groups is too small to generalise, that the factor continued in this group to increase with age certainly up to 23. The unemployed group shows that the factor was definitely below that of the employed factory groups and that it falls with advancing years (see also fig. XV)

We took the opportunity whilst working through these strength tests to check a statement of Whipple [21] that the back lift (our lumbar pull) is roughly 3·2 times the strength (grip) of the right hand. Table XXXVI gives the results of the calculation on this basis of our data for the employed and unemployed factory women and the college women worked out in age groups. It shows that the average value for the employed factory women is 3·1, for the unemployed 3·0 and the college women 3·4. Whipple's conclusion is thus confirmed.

TABLE XXXVI.—*Relation of Pull to Grip*

Age Group	Mean Pull	Mean Grip	Pull / Grip
	Factory Women.		
$14^0/_{12}$–$14^5/_{12}$	63·5	21·0	3·0
$14^6/_{12}$–$15^5/_{12}$	72·3	23·4	3·1
$15^6/_{12}$–$16^5/_{12}$	78·6	25·3	3·1
$16^6/_{12}$–$17^5/_{12}$	79·6	25·7	2·1
$17^6/_{12}$–$18^5/_{12}$	83·7	26·6	3·1
$18^6/_{12}$–$19^5/_{12}$	85·1	26·7	3 2
$19^6/_{12}$–$20^5/_{12}$	83·6	26·5	3·2
$20^6/_{12}$–$21^5/_{12}$	85·3	27·2	3·1
$21^6/_{12}$–$22^5/_{12}$	85·2	26·9	3·2
$22^6/_{12}$–$23^5/_{12}$	84·3	27·1	3·1
$23^6/_{12}$–$24^5/_{12}$	88·0	27·6	3·2
$24^6/_{12}$–$25^5/_{12}$	85·5	26·6	3·2
$25^6/_{12}$–$26^5/_{12}$	86·8	27·1	3·2
$26^6/_{12}$–$28^5/_{12}$	85·2	27·6	3·1
$28^6/_{12}$–$30^5/_{12}$	82·5	26·4	3·1
$30^6/_{12}$–$40^5/_{12}$	87·0	27·2	3·2
$40^6/_{12}$–$55^5/_{12}$	80·9	26 0	3·1
Average	—	—	3·1
	Unemployed Women.		
$19^6/_{12}$–$24^5/_{12}$	75·4	25·2	3·0
$24^6/_{12}$–$34^5/_{12}$	75·4	24·9	3·0
$34^6/_{12}$–$55^5/_{12}$	73·4	24·4	3·0
Average	—	—	3·0
	College Women.		
$18^6/_{12}$–$19^5/_{12}$	96·6	29·1	3·3
$19^6/_{12}$–$20^5/_{12}$	96·1	27·6	3·5
$20^6/_{12}$–$21^5/_{12}$	99·0	28·7	3·4
$21^6/_{12}$·$23^5/_{12}$	100·6	28·7	3·5
Average	—	—	3·4

Civil State

In the course of collecting the data, as will be noted from the card, the question whether the worker was married, single or widowed was noted. The majority of the women examined were single. Some of the firms who granted us access employed no married women but in this respect the cotton trade is a notable exception. Weaving in Lancashire is and has been since the industrial revolution a woman's trade and one which requires a good deal of training. In a factory visited in the course of this investigation there was a special school for the training of weavers for girls aged 14–16. Marriage for the woman employed in this trade does not mean a complete break with their work as they frequently hire help for looking after their houses and children. Table XXXVII gives some information about the number of married women employed in the cotton trade in comparison with the number in a random sample of the same size (300), taken from the other trades investigated Columns B and C of the table are very interesting, although the numbers are not sufficiently large to permit of any generalisation.

TABLE XXXVII.—*Married Women in Cotton and other Industries.*

Sample	A	B	C
	Per cent of Women Married	Per cent. of Married having less than 2 Children	Per cent of (B) over 25 years of age
Cotton Trades . .	27	71	83
Random Sample of all other Trades	13	60	76

Geographical and Racial Differences.

When collecting our data we thought it would be of interest to note any geographical or racial differences which might exist amongst the various workers. The racial data, such as they are, are deduced from the race of the father and mother of the worker This unfortunately does not carry us very far, as in Glasgow, at least, and almost certainly elsewhere, a girl may state that her father and mother for instance were Scots in so far that they were both born in Scotland, and no doubt legally were Scots, yet very often the parentage might be and probably was in many instances pure Irish in the third generation back. As we had neither the time nor the means to check the hereditary factors, our data must be considered as but an approximation and must be used with great caution.

In considering differences in physique in different geographical areas one is really only viewing from another aspect the problem of racial differences or the racial ancestry of the population.

The Report of the Anthropometric Committee of the British Association [7] forms the foundation of our knowledge of this problem. The report contains tables of stature and weight and details of pigmentation of the population (for the most part males) in all parts of the British Isles and states that the variations shown "appear to be chiefly due to differences of racial origin, and this influence predominates over all others." The report also adds that "the inhabitants of the more elevated districts possess a greater stature than those of the alluvial plains" even when the racial origin is similar and also "the inhabitants of the northern and colder districts possess greater stature than those of the southern and warmer parts of the island . . . . . a similar disposition of stature has been found to exist in France and Italy." Muscio [14] (1922), in his study of the physical strength of Manchester and Essex adolescent males, obtained marked differences between his country and urban youths. He found that in weight, height and grip the Essex adolescent male is superior to his Manchester brother, and concluded, therefore, that no one norm of strength would serve for the whole county.

The present investigation, like Muscio's, was concerned with the industrial population, so that there was no question of comparing persons living at different heights We did not deal with the complete mass of data at our disposal, as from a preliminary survey we did not consider that the results to be obtained would justify the labour involved in working up the data. We took four age groups for special study, 18 years, 23 years, 29–30 years and 41–55 years. These particular age groups give samples of women before the end of adolescence (18 years) accepting the statement of the B.A. Anthropometric Committee that maturity in the female is reached at 20 years, two samples during the period of maturity (23 and 29–30 years groups) and one sample of women of middle age.

The women investigated fall into four groups—those at factories in and round London, those in the Midlands (the Potteries, Stafford, Birmingham, Coventry and Stowbridge), those in Lancashire (Preston and Blackburn), and those in Glasgow. Except for the Lancashire district, where in each age group the numbers are quite small, there are approximately equal, although still small, numbers of women in the London, Midland and Glasgow districts.

It may be quite frankly stated that the results we obtained from the selection of our data are too variable to be of any real value (see Tables XXXVIII and XXXIX). It will be noted that neither in the physical measurements nor in the strength tests do the women in any one area take precedence in all age groups. Table XL gives the various orders of precedence found, although, owing to the small numbers compared, no definite

TABLE XXXVIII.—*Geographical Distribution (Physical Measurements)*

District.	AGE GROUP.											
	18 years.			23 years.			29 and 30 years			41–55 years		
	No.	Mean Weight.	Mean Height.	No.	Mean Weight.	Mean Height.	No	Mean Weight.	Mean Height.	No	Mean Weight.	Mean Height.
London District ..	57	49·83	158·3	44	50·44	158·1	17	51·68	159·6	21	54·44	157·7
Midlands	79	49·90	157 5	85	47·53	156·7	46	50·33	157·3	29	52 63	157·2
Lancashire	15	45·79	157·9	12	49·73	156·7	15	47·97	156·5	29	51·02	155·4
Glasgow District ..	97	51·64	157·2	48	52·25	157·7	28	49·09	154 1	14	60·65	156·8
Whole Age Group	259	50·19	158·2	197	49·60	157·3	116	50 11	156·5	104	54·10	156·6
S.D.	—	6·49	5·4	—	7·19	5·5	—	6·96	6·1	—	9·06	5·2
C. of V.	—	12·93	3·4	—	14·49	3·5	—..	13·9	3·9	—	16·75	3·3

TABLE XXXIX.—*Geographical Distribution. (Strength Tests).*

District.	AGE GROUP.															
	18 years				23 years				29 and 30 years.				41–55 years			
	No. in Group	Mean Pull	Mean Grip.	Mean Crush	No. in Group.	Mean Pull.	Mean Grip	Mean Crush.	No in Group	Mean Pull.	Mean Grip.	Mean Crush.	No. in Group	Mean Pull.	Mean Grip.	Mean Crush.
London District	57	82·5	27·0	23·7	44	83·8	27·9	22·3	17	83·0	27·1	23·1	21	75·9	25·5	19·9
Midlands ..	79	84·6	27·3	21·0	85	83·7	27·4	21·9	46	86·4	26 4	23·4	29	91·6	26·2	20 1
Lancashire ..	15	72·1	28·4	22·6	12	84·9	26·8	23·7	15	76·4	28·0	20·8	29	72·1	26·3	18·5
Glasgow District	97	84·3	24·8	22·4	48	83·8	26·3	21·5	28	76·0	24·7	20·5	14	83·3	25·9	20·2
Whole Age Group	259	83·7	26·6	23·5	197	84·3	27·1	22·6	116	82 5	26·4	22·1	104	80 9	26 0	19·4
S.D. .	—	14·8	4 8	6·2	—	17·8	5·3	5·8	—	17·7	4·5	6·5	—	21·5	4·9	5·4
C. of V .	—	17 7	17·9	26·4	—	21·1	19·6	25·8	—	21 4	17·2	29·4	—	26·6	18 9	28·0

deduction can be drawn from this table. Thus it will be noted that as regards weight Glasgow takes first place in age groups 18, 23 and 41–55, but only third place in age group 30. London women take first place for height in all age groups. As regards pull the Midlands take first place in age groups 18, 30 and 41–45, with grip Lancashire takes first place in groups 18, 30 and 41–45; and with crush all four districts take first place in turn. No one group is consistently high or low. As the number of women in each group available for comparison was so small and the results, therefore, were of very limited value, we did not consider it necessary to determine the significance of the differences found between the various groups. Casual examination will show that it is almost certain that the order of precedence given is, in certain instances at least, of no significance whatsoever.

Muscio in his work [14] found an average difference in strength of grip of 4·3 kilos between the Essex and Manchester youths he examined The results of our investigation, however, do not support his findings, as in each age group there is comparatively little deviation for each district from the mean of the whole group.

One of the chief objects of the survey made by the British Association Anthropometric Committee [7] was to ascertain the principal physical characteristics of the adult population of the whole country and of each of its four provinces.

TABLE XL —*Geographical Distribution.*

Age Group 18 Years				Age Group 29 and 30 Years.			
Wt	(97) Glasgow	51·64	50·19	*Wt*	(17) London	51·68	50·11
	(79) Midlands	49·90			(46) Midlands	50·33	
	(57) London	49·83			(28) Glasgow	49·09	
	(15) Lancs	45·79			(15) Lancs	47 97	
Ht	London	158·3	158·2	*Ht*	London	159·6	156·5
	Lancs	157·9			Midlands	157·3	
	Midlands	157·5			Lancs	156·5	
	Glasgow	157·2			Glasgow	154·1	
Pull	Midlands	84·6	83·7	*Pull*	Midlands	86·4	82·5
	Glasgow	84·3			London	83·0	
	London	82·5			Lancs	76·4	
	Lancs	72·1			Glasgow	76·0	
Grip	Lancs	28·4	26·6	*Grip*	Lancs	28·0	26·4
	Midlands	27·3			London	27·1	
	London	27·0			Midlands	26·4	
	Glasgow	24·8			Glasgow	24·7	
Crush	London	23·7	22·4	*Crush*	Midlands	23·4	22·1
	Lancs	22·6			London	23·1	
	Glasgow	22·4			Lancs	20·8	
	Midlands	21·0			Glasgow	20·5	

TABLE XL.—*Geographical Distribution*—contd.

	Age Group 23 Years				Age Group 41–55 Years.		
Wt. ..	(48) Glasgow ..	52 25	49·60	*Wt* ..	(14) Glasgow ..	60·65	54·10
	(44) London ..	50·44			(21) London ..	54·44	
	(12) Lancs ..	49·73			(29) Midlands..	52·63	
	(85) Midlands..	47 53			(29) Lancs ..	51·02	
Ht. ..	London ..	158·1	157·3	*Ht* ..	London ..	157·7	156·6
	Glasgow ..	157·7			Midlands..	157·2	
	Midlands	156·7			Glasgow ..	156·8	
	Lancs				Lancs ..	155·4	
Pull ..	Lancs ..	84·9	84·3	*Pull* ..	Midlands..	91·6	80·9
	Glasgow	83 8			Glasgow ..	83·3	
	London				London ..	75·9	
	Midlands..	83·7			Lancs ..	72·1	
Grip .	London ..	27·9	27·1	*Grip* ..	Lancs ..	26·3	26·0
	Midlands..	27·4			Midlands..	26·2	
	Lancs ..	26·8			Glasgow ..	25·9	
	Glasgow ..	26·3			London ..	25·5	
Crush	Lancs ..	23·7	22·6	*Crush*	Glasgow ..	20·2	19·4
	London ..	22·3			Midlands .	20·1	
	Midlands..	21·9			London ..	19·9	
	Glasgow ..	21·5			Lancs ..	18·5	

As the result of this survey they found that the Scots took first place both as regards weight and height, the Welsh were next heaviest followed by the English then the Irish. In height the Irish were second followed in turn by the English and Welsh. These deductions were made from the examination of the male population, the only females, and those very limited in number, examined being English.

In the present investigation the sample of women born in Scotland was drawn almost entirely from Glasgow. In view of the aim of our investigation we had little chance of going further afield, but we regret the necessity of the choice as it has been clearly shown that the inhabitants of Glasgow are not a true sample of Scots. The work of Gray [22] and of Tocher [23] on the pigmentation of school children in Scotland has, for instance, shown that, so great is the divergence of the population of Glasgow in hair and eye colour from Scotland as a whole, that " the odds against the population of Glasgow being a random sample of Scotland is $10^{43\cdot 6}:1$. These odds are more than enough to establish the important conclusion that the population of Glasgow (in so far as it is correctly represented by the school children observed) has been so much changed by an urban environment and by alien immigration that it can no longer, as a whole, be regarded as Scotch." (Gray).

The Irish women investigated were found principally in Glasgow along with a few in Lancashire and the Midlands.

As in the geographical division we utilised the same age groups of factory women, viz., those of 18, 23, 29–30 and 41–55 years. Each of these age groups was separated into four classes: those whose parents were both Scots (remembering the limitation referred to in the previous section on geographical distribution), both Irish or both English and finally those whose parents were of different races (" mixed "). In all the age groups, as may be noted from Tables XLI and XLII, the " pure " English form the largest percentage with the " pure " Scots next.

Here again, as in the geographical differences, the results are strikingly inconsistent. Table XLIII gives the order of precedence in each particular. As regards weight it will be noted that the Scots are heaviest in the first age group, the Irish in age groups 23 and 41–55, and those of mixed parentage in the 29–30 group. In height the English takes first place in age groups 18 and 29–30, the " mixed " have precedence in group 23 and the Irish in age group 41–55 Even where strength is concerned the three tests we employed do not give uniformity even within the limits of a single age group.

As the numbers in the Irish and mixed group are so infinitesimal, the deductions drawn in respect to them are of no real value. When these are omitted and the two larger groups of the English and the " Scottish " are compared it is still found that there is a lack of uniformity. The English women take first place in age group 18 in height, grip and crush, the " Scots " in weight and pull. In age group 23 the Scots take precedence in weight, height and pull, the English in grip and crush The English in age group 29–30 take first place throughout and in age group 41–55 the " Scots " take the lead in weight and pull and the English in height, grip and crush.

The results then are quite inconclusive, probably owing to the fact that the numbers compared are so small.

In addition to the racial character of the women examined we collected data as to where they were born and bred, i.e. whether they had been born and brought up in the country or in a town.

Influence of Environment.

The problem of the influence of an urban environment on a population is one which has frequently been debated. The earliest investigations that we know of, in which urban and rural populations were compared, are those of Villerme [24] and of Quetelet [25]. Since then a great deal of valuable work has been done, and not the least valuable by Galton and Pearson. But when all the data are examined (Ripley in his " Races of Europe " [26] gives a good summary) it is very obvious that they almost entirely relate to the measurement of men. Data with reference to women are very scanty. It is true that the Anthropometric Committee did obtain returns for under 400 women, and Galton and Pearson have also given certain details of a number of women,

TABLE XLI.—*Racial Differences.*

Race.	Age Group															
	18 years.				23 years				29 and 30 years				41–55 years			
	No in Grp	Mean Weight	Mean Height	Mean Pull	No in Grp	Mean Weight	Mean Height	Mean Pull	No in *Grp	Mean Weight	Mean Height	Mean Pull.	No. in Grp	Mean Weight.	Mean Height	Mean Pull
Pure English	150	49·50	158·9	83·9	142	48·66	157 0	82·5	82	50·29	157·4	83·7	79	52·56	156·5	79·7
" Pure Scots "	79	51·89	157·8	84·8	37	50·62	157·2	83·7	23	49·29	155·0	77·1	15	57·21	156·4	84·7
Pure Irish ..	5	47·55	158·6	83·3	5	59·36	158·6	85 4	5	47·42	156·0	73·1	5	63·73	158·7	92 3
Mixed Parentage	25	50·14	155·1	79·3	13	52·66	160·2	91·2	5	50·54	151·0	97·6	5	60·18	156·7	74·6
Whole Age Group	259	50 19	158·2	83·7	197	49·60	157·3	84·3	116*	50·11	156·5	82·5	104	54·10	156 6	80·9
S D. ..	—	6·49	5·4	14·8	—	7·19	5·5	17·8	—	6·96	6·1	17·7	—	9·06	5 2	21 5
C. of V. ..	—	12·93	3 4	17·7	—	14·49	3·5	21·1	—	13·9	3·9	21·4	—	16·75	3·3	26·6

* One girl in this group, parents both Welsh

TABLE XLII.—*Racial Differences.*

Race.	Age Group											
	18 years			23 years.			29 and 30 years.			41–55 years.		
	No in Group	Mean Grip	Mean Crush.	No in Group	Mean Grip	Mean Crush	No in Group	Mean Grip	Mean Crush	No in Group	Mean Grip	Mean Crush
Pure English .	150	27·4	24·3	142	27·4	22·7	82	27·0	22 6	79	26 1	19·7
" Pure Scots "	79	25·8	21 2	37	25·6	20·9	23	24·9	20·4	15	25 1	19·5
Pure Irish ..	5	29 0	23·2	5	27 6	21·8	5	23 4	20·7	5	28 6	20·0
Mixed Parentage	25	25·0	21·7	13	29·9	25 8	5	26 6	24 3	5	25 6	18·4
Whole Age Group	259	26 6	23·5	197	27·1	22 6	116*	26·4	22·1	104	26·0	19·4
S D. .	—	4·8	6·2	—	5·3	5 8	—	4·5	6 5	—	4·9	5·4
C. of V. ..	—	17·9	26 4	—	19 6	25 8	—	17 2	29·4	—	18 9	28·0

* One girl's parents, both Welsh.

TABLE XLIII.—*Racial Differences.*

Age Group 18 Years

Wt.	(79)	" Scots "	.. 51·89	50·19
	(25)	Mixed	.. 50·14	
	(150)	English	.. 49·50	
	(5)	Irish..	.. 47·55	
Ht.		English	..158·9	158·2
		Irish	..158·6	
		" Scots "	..157·8	
		Mixed	..155·1	
Pull.		" Scots "	.. 84·8	83·7
		English	.. 83·9	
		Irish	.. 83·3	
		Mixed	.. 79·3	
Grip.		Irish..	.. 29·0	26·6
		English	.. 27·4	
		" Scots "	.. 25·8	
		Mixed	.. 25·0	
Crush.		English	.. 24·3	23·5
		Irish..	.. 23·2	
		Mixed	.. 21·7	
		" Scots "	.. 23·2	

Age Group, 29 and 30 Years.

Wt.	(5)	Mixed	.. 50·54	50·11
	(82)	English	.. 50·29	
	(23)	" Scots "	.. 49·29	
	(5)	Irish..	.. 47·42	
Ht		English	..157·4	156·5
		Irish..	.156·0	
		" Scots "	..155·0	
		Mixed	.151·0	
Pull		Mixed	.. 97·6	82·5
		English	.. 83·7	
		" Scots "	.. 77·1	
		Irish..	.. 73·1	
Grip		English	. 27·0	26·4
		Mixed	26·6	
		" Scots "	.. 24·9	
		Irish	. 23·4	
Crush		Mixed	. 24·3	22·1
		English	.. 22·6	
		Irish..	.. 20·7	
		" Scots "	.. 20·4	

Age Group, 23 Years.

Wt.	(5)	Irish.	.. 59·36	49·60
	(13)	Mixed	.. 52·66	
	(37)	" Scots "	.. 50·62	
	(142)	English	.. 48·66	
Ht		Mixed	..160·2	157·3
		Irish	..158·6	
		" Scots "	..157·2	
		English	..157·0	
Pull.		Mixed	.. 91·2	84·3
		Irish	.. 85·4	
		" Scots "	.. 83·7	
		English	.. 82·5	
Grip.		Mixed	.. 29·9	27·1
		Irish	.. 27·6	
		English	.. 27·4	
		" Scots "	.. 25·6	
Crush.		Mixed	.. 25·8	22·6
		English	.. 22·7	
		Irish	.. 21·8	
		" Scots "	.. 20·9	

Age Group, 41–55 Years.

Wt.	(5)	Irish	.63·73	54·10
	(5)	Mixed	..60·18	
	(15)	" Scots "	..57·21	
	(79)	English	..52·56	
Ht.		Irish	..158·7	156·6
		Mixed	..156·7	
		English	..156·5	
		" Scots "	..156·4	
Pull		Irish..	.. 92·3	80·9
		" Scots "	.. 84·7	
		English	.. 79·7	
		Mixed	.. 74·6	
Grip		Irish	.. 28·6	26·0
		English	.. 26·1	
		Mixed	.. 25·6	
		" Scots "	.. 25·1	
Crush.		Irish	.. 20·0	19·4
		English	.. 19·7	
		" Scots "	.. 19·5	
		Mixed	.. 18·4	

but these cannot be considered as a representative sample of the general population. This the Anthropometric Committee fully recognised, as they write that their data "were obtained from pupils in training institutions for school mistresses and from shop assistants" The report adds ". . . . and the average is no doubt much lower than if the labouring classes were also represented." The data we collected are also admittedly drawn from one stratum of society, but the sample is large, it is representative, and it was collected personally throughout by the same investigators It gives, we believe, a good representation of the physique of the women at present engaged in industrial pursuits.

As regards the special point at issue: the differences, if any, between the urban and rural populations, Quetelet [25] found for instance that the urban population of Belgium was both taller and heavier than the surrounding rural population. The mass of data which has been accumulated since Quetelet's day goes to show, however, that this conclusion is not well founded. The probable explanation of this divergence is that Quetelet in his investigation not merely compared urban and rural men, but men of different social status. The work, for example, of the Anthropometric Committee [7] and of Beddoe [27] has shown quite definitely that if care be taken to compare people of the same social level, the urban population has a smaller height and weight than the rural.

Stress has been laid on the fact that in making these comparisons persons of the same social class must be utilised. The reason for this stress is shown both in the work of Beddoe and of the Anthropometric Committee just referred to. The Committee found a decrease in median stature in passing from the professions through the commercial, labouring and artisan classes to the men engaged in sedentary factory occupations. Ripley [26], too, has stressed this point in a different fashion when he writes, "in the wards of the city where prosperity resides the material well-being tends to produce a stature distinctly above that of the slums." (P. 380.)

One of the most important features of urban populations then is this tendency to divergence in physical measurement. To quote Ripley again, "compared with the rural districts, where all men are subject to the same conditions of life, we discover in the city that the population has differentiated into the very tall and the very short."

There are several ways of regarding this development in the urban population. This differentiation of the tall and the short may possibly be due to the fact that the tall are in reality incomers, the big vigorous men who have the initiative and energy to leave their country homes and take part in the more adventurous life of the city, or else the urban population is built up from a stock who are physically inadequate for the strenuous and rigorous life of the agricultural labourer; or, finally, that speaking generally the tall man is unfitted physically for the relatively cramped

life of the average industrial workshop and he inevitably moves on to work more suited to his physique, leaving industry in the hands of the smaller and, in this particular respect, the fitter race.

So far as we know there has been heretofore no comparison made between the physique of urban and rural women. In our work we attempted to avoid the fallacy of utilising different social status in comparisons. We therefore considered separately the college and factory women. The difficulty lay, however, in the definition of the limits of "town" and "country," since the suburb is becoming more and more a feature of modern life. In this analysis, therefore, suburban residents were excluded, the only cards used being those of women who had been born and brought up in a definite town or a definite rural area. Here it is necessary to differentiate between the life of the country bred college women and the country bred factory woman. In this sample here studied a country bred college woman is one who was born and spent all her life up to the age of 17 or 18 in the country. The college which she comes to at that age is situated at Jordanhill in the West-end of Glasgow, on high ground and in an environment which certainly may be termed "countrified" If her home is at some distance she must stay either in the college or within a reasonable distance of it.

On the other hand the "country bred factory woman," although she has been born and bred in the country, starts factory work probably at the age of 14. The fact that she is able to get in to a factory at all means that either her country home is quite near an industrial town, or that she works in a, probably modern, factory built in the country.

The chief difference, therefore, between the country bred college and factory woman lies in the fact that the college women have three or four years more of a purely country life, these years from 14 to 17 or 18 being among the most important in the women's life time for growth and development.

In order to make the comparison as fair as possible a sample was taken in each group of women aged $18\frac{6}{12}$ to $23\frac{5}{12}$. Table XLIV gives the mean weight, height and strength tests for each sub-divided group and incidentally shows most clearly the very much greater number of country bred college women who form 56 per cent. of the total college women compared with country bred factory women who only form 10 per cent. of the total factory women.

As regards weight and height the country bred college women exceed the town bred by 3·14 kilos or nearly 7 lb.; in height by 1 cm. or about 0·4 of an inch. In the case of the factory women again, in weight the country bred exceed the town bred by 1·26 kilos or just over $2\frac{3}{4}$ lb., but are 0·8 cm. or about one-third of an inch less in height. It is very doubtful, however, if much significance attaches to this small difference since the number of pure country bred women is so small.

TABLE XLIV.—*Comparison of Country and Town-bred Women.*

Ages $18^{6}/_{12}$–$23^{5}/_{12}$	No	Mean Weight. kilos.	Mean Height. cm.	Mean Pull kilos	Mean Grip. kilos	Mean Crush. kilos.
College Women—						
Country Bred .	203	54·39	161·5	93·7	29·2	27·0
Town Bred ..	161	51·25	160·5	96 8	27·9	26·3
Factory Women—						
Country Bred ..	23	51·87	157·8	82·5	25·9	23·3
Town Bred .	199	50·61	158·6	84·6	26·8	23·7

Whatever may be their value these figures certainly show a greater weight for country bred women whether they be taken from college or factory. The height of the country bred college women is definitely above that of the town bred women and, although this result is not supported by the means of the factory group, the results as a whole support the great bulk of the evidence previously adduced.

Our comparative examination of the strength tests has produced some interesting results. In the case of "lumbar pull" the mean obtained by the country bred college women is 3·1 kilos less than that of the town bred and with the country bred factory women it is 2·1 kilos less than that of the town bred. These results are rather unexpected especially if the strength of pull were in any great measure a function of body weight. It will be remembered that the correlation coefficients for weight and pull both in college and factory women were not very significant. With grip the country bred college women were 1·4 kilos better than the town bred, but in the case of the factory women the mean grip of the country bred was less by 0·9 kilo than that of the town bred. Finally, with crush the same curious inversion between college and factory women was found, the country bred college women having a crush exceeding that of the town bred by 0·7 kilo; on the other hand the town bred factory women having a crush of 0·4 kilo better than the country bred women.

In these tests of grip and crush then the college group of country bred women exceed the town bred, and the opposite result is found in the factory group, although in each test the differences obtained are very small. The implications of the strength tests—how far they reflect actual muscular strength and how far they indicate differences in mental alertness and power of co-ordination—are very difficult to formulate. The conclusion, however, of Martin has already been referred to (see page 48). It is, however, interesting to note here that in one factory in the country it was stated that although the country girls were cleaner and therefore for the particular work done (manufacture of confectionery) more desirable, they were slower workers than the town bred girls.

There is no doubt then that speaking generally the physique of the town dweller is inferior to that of the country dweller. To what is this to be ascribed? Beddoe in 1870 [27] advanced four main causes to account for the variations in stature existing in "townsmen and artisans" His causes may be grouped as follows :—

1. Birth and rearing in town and country.
   (*a*) Influences prior to birth The chief of these being the influence of race, hereditary diseases or weaknesses.
   (*b*) Influences subsequent to birth. Gross errors in upbringing of children. Chief among these he classes deficiency of breast milk in town mothers and want of a good supply of cow's milk in town.
2. Selection and elimination.
   (*c*) Natural or spontaneous. For example, differences in temperament which determine the occupations and therefore probably the "build" of the individual, and natural elimination by disease.
   (*d*) Artificial. For example, the selection that sends a strong lad into a heavy trade.
3. Nature of employment. Environmental conditions, mode of work, size of wage.
4. Habits of life during youth. For example, the want of opportunity and stimulus for the development of their physical powers by young persons in towns, etc.

It is interesting to contrast this summary of 56 years ago with the findings of Professors Noël Paton and Findlay [28] in their report on poverty, nutrition and growth of children in cities and rural districts of Scotland. This investigation, begun in 1919, was an enquiry into the effect on town and country children of poverty, bad housing, various ante-natal influences and maternal efficiency. The only really significant correlation which these investigators found in the whole series was that between maternal efficiency and weight of child, although, at the same time, it must be remarked that this positive correlation was not sufficiently high to indicate that maternal efficiency is the only factor modifying the physique of children. It is interesting to note that there is no real evidence that the purely environmental factors played an important role. In this connection we would again refer to the fact that one of the finest groups of women studied by us had been born and bred in one of the bad slum areas of Glasgow. Although Professors Noël Paton and Findlay's report deals with the child life of the present day, its conclusions probably hold good for the child life of 14 to 20 years ago, i.e., when the majority of the women dealt with in this report were children.

Therefore, although this investigation can throw no further light on the causes of variation between town and country populations, its results, so far as height and weight are concerned, fall into line with the previous work on men.

Summary.

1 Anthropometric measurements of 4,366 women have been made They were divided as follows :—

Women engaged in industry ..	3,076
Unemployed women	413
College women	460
Women engaged in heavy trades	417

The employed women were drawn from 26 different factories lying between Glasgow and London

2. Average data obtained were as follows :—

	Weight. kilos.	*Height. cm*	*Pull kilos.*	*Grip. kilos*	*Crush. kilos.*
Employed women	49·67	157·3	83·2	26·4	22·6
Unemployed ,,	49·60	152·2	75 1	24 9	19·1
College ,,	53·01	160·97	97·9	28 5	26·7

3. The average elbow height of the women was 39·9 inches. Hence it follows that the comfortable height of a working bench for the average woman standing should be about 37 inches

4. A large number of correlations were carried out but no very significant relation was found.

5. There is a certain amount of evidence to show that there is some relation between the "heaviness" of the trade and the physique of the women employed in it.

6. The variation in physique, and its possible significance, between the different groups is discussed.

7. The attempt to obtain some standard specification for the classification of workers in terms of fitness has not been very successful. The total strength-weight ratio is, however, strikingly uniform for workers in good condition. If this ratio be taken as the criterion of fitness, we find that the average value for the employed group is about 2·66, for the unemployed about 2·38, and for the college girls 2·88. On the basis of our data women with a "fitness factor" below 2·5 may be considered as probably unfitted for hard factory work, although they may still be suited for some lighter occupation.

8. Whipple's statement that lumbar pull is roughly 3·2 times greater than the grip of the right hand is corroborated.

9. An attempt was made to determine anthropometric differences due to geographical and racial distribution. Our results, probably on account of the fewness in number in each group, gave results too variable to be of value.

10. Our evidence, such as it is, supports the general belief that the rural population is of better physique than the urban.

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PART II.—DETERMINATION OF OPTIMUM LOAD

Introduction.

In a previous paper, Report No. 29 of the Industrial Fatigue Research Board, an analysis was made of the differences of the energy expenditure of a woman who was required to carry identical loads (from 20 to 60 lb) by eight different methods It appeared from this work that the metabolic costs, and also, in a general way, the subject's comfort and capacity for work, were determined by four principal factors :—

1. The existence of any local strain or discomfort
2. The degree of interference with the free movement of the legs in walking
3. The extent to which the normal carriage of the body has to be altered to counterbalance the load, i e, the displacement of the centre of gravity.
4. The degree of chest-fixation, with associated interference with respiratory and circulatory junctions.

Of these four factors, the first is of great practical importance in industry, since under its heading may be considered many problems, such as the suiting of heights of benches, sizes of trays, and so forth, to the actual physique of the workers using them, or the selection of women of suitable build, arm-length, and muscular capacity, for the work required of them. For theoretical analysis in the laboratory, however, this first factor does not offer a particularly fruitful field of enquiry, as the "personal factor" will be too prominent where only one or two subjects are used, and these subjects, moreover, being unaccustomed to continuous work of the kind, may be at the stage when "local strains and discomforts" tend to be rapidly modified by practice.

The second factor, that of interference with the normal movement of the limbs, presents some points of considerable theoretical interest, and might well be further developed.

The present contribution is chiefly concerned with some further observations designed to confirm or modify the deductions previously made as to the influence of the third and fourth factors.

It appeared that there was a definitely significant correspondence between metabolic costs and those adjustments of posture which are required to compensate for the alteration of the centre of gravity caused by the addition of the load. It was desired to verify this point by introducing finer distinctions in the degree of body-displacement required, as, for example, by making up the load to be carried on the hip in three different bulks, of which the widest would require a large lateral curvature of the body, while the most concentrated would allow of a fairly normal posture. Further, it seemed advisable to check the former results by repeating as many of the experiments as possible on a subject of quite different physique and habit.

The fourth factor, which was summarized under the name of chest-fixation is analogous to the general stiffening of the trunk muscles used by athletes in order to give the firmest support possible to the taxed muscles of the shoulder or pelvis girdle. Such static muscular contraction is in itself a costly form of physiological effort, but of greater importance than the extra oxidation directly due to it are the indirect reactions of the fixations of chest-walls and diaphragms on the respiratory and circulatory functions

It is, of course, easily observed that compensatory changes in these functions result from any abnormal posture of the thorax, even with a light load or indeed with no load ; apart, that is, from any considerable demand upon the thoracic muscles to reinforce the efforts of the limb muscles. It will probably be only in cases where large demands for oxygen coincide with a large degree of fixation due to an awkward disposition of the load, that there will be any question of *excessive* taxing of the wonderfully efficient self-regulating cardio-respiratory system.

It was felt that the reactions of the circulatory system might form a better index of the organism's capacity for the task imposed than any other measurable physiological effect, and that light could be shed on the vexed question of the " maximum safe load " if really reliable data, in sufficient quantity, could be collected from normal working women. The practical difficulties of making such observations are, however, with our present equipment, insuperable, and even under laboratory conditions they are very great. As shown in Report No. 29, satisfactory measurements of blood-pressure and even of pulse-rate were not easily achieved in the form of experiment found most suitable for the metabolic assessment The second part of the present paper, however, includes a large number of observations made under more favourable conditions, which are reliable, as far as they go, and show some rather interesting parallels with the metabolic data in the extent and duration of the circulatory accommodation induced by various loads and methods of carriage

Further Observations on the Energy Expenditure of Women in Carrying Loads in Various Positions.*

EXPERIMENTAL PROCEDURE AND CONDITIONS.

The performance of an hour's work at set pace, alternately carrying a load for a circuit of 100 yards, and walking the circuit unloaded, was conditioned and carried out as described on pp 5–7 of Report No. 29. The only differences were that all the experiments were carried out between 2 30 and 4 30 p.m., instead of in

* The experiments reported in this section are exactly similar in plan and technique to those described fully in Report No 29 of the Industrial Fatigue Research Board (The Effects of Posture and Rest in Muscular Work), and reference to its paragraphs will obviate the necessity for much repetition of detail here

the morning; and that, except in the case of carrying on the yoke, no empty box or other appliance was carried in the "unloaded circuit."

In addition to the Subject (A) previously used (see p. 7 of No. 29) we were able to repeat a large number of the metabolic experiments on a younger woman (B), of unlike build, habits and temperament. Again a subject was deliberately chosen who had no previous experience of the carriage of loads. We consider that such a subject is absolutely essential (*v.* p. 3 Report No 29) if reliable comparative data are to be obtained. True, the physiological costs as compared with a woman skilled in some particular mode of carriage may be higher but they will be no higher, indeed the chances are they will be somewhat lower, than those of the trained woman in method X carrying by methods Y or Z as the psychological disturbance of carrying by a new and resented method will be absent. This subject (ht. 162 cms., av. weight clothed 65·4 kg., surface area 1·70 sq. m., age 24 years) was in good health, but hardly in "good training" She usually took little exercise beyond what was entailed by the experiments She lost over 3 kg. in the first two or three weeks of the work, and did not regain her initial weight, but throughout the experiments her body weight varied considerably, as may be detected in the tables which follow, from the column of horizontal kgm. of total work performed. B was able to do most of the experiments without serious difficulty, but she appeared to suffer more than A from local pains and strains, while perhaps less from any after-sensation of general fatigue. Subjectively, she distinctly experienced a feeling of improvement with practice, and there is objective evidence in the tables that training—even the very small amount of special training that the plan of the work allows—made a greater difference to her than to A.

BASE LINES FOR CALCULATION OF NET RESULTS.*

Opportunities for observing B's true basal metabolism were not available. Her resting metabolism, determined before each experiment, shows averages appreciably lower than A's.

TABLE XLV.—*Resting Metabolism before Work Average* Table III, p. 9 of No. 29.)

CO_2 *per min. c.c.*	O_2 *per min. c.c.*	*Standard Deviation*† O_2.	*Cal. per hour per sq. metre.*
A. 186	219	12·4	38·2
B. 154	192	11·3	33·03

† O=Oxygen determinations.

The cost of walking at the experimental pace and under the same conditions, with no load beyond the respiratory apparatus, was found in B's case to be as shown below. While body weight,

* See p. 8 of No. 29.

and energy expenditure per unit time, are different in the two subjects, the cost per horizontal kilogrammetre (hor. kgm) of transporting the body appears (on the averages of only small numbers of experiments) to be identical.

TABLE XLVI.—*Walking. Average net values.*

CO_2 *per min. c c.*	O_2 *per min. c.c.*	*Standard Deviation** O_2.	*Cal. per min.*	*Hor. kgm per min.*	O_2 *per hor. kgm.*	*Gram. cals. per hor. kgm.*
A. 343	421	22·7	2·01	4,403	0·96	·46
B. 374	484	21·5	2·346	5,051	·096	·46

* O=Oxygen determinations.

THE EXPERIMENTS.

The following methods of load-carrying, already assessed in Subject A, were repeated on Subject B :

1. Weight spread over a tray, carried in front of the body
2. Weight distributed on a board, carried on the shoulder.
3. Weight carried in a tray on the hip.
4. Weight divided between two pails and carried on a shoulder-yoke.

In amplification of these, the following methods were examined :—

1*a*. Weight spread over a *narrower* tray, carried in front. B.

1*b*. Weight concentrated in small bulk, slung in an apron and carried close against the front of the body. A and B.

3*a*. Weight carried in a *narrower* tray on the hip. A and B.

3*b*. Weight concentrated, carried on hip close under the arm. A and B.

5. Weight concentrated, carried on the head. A (as addendum to Mode 8 of previous work).

1. *Load carried in front of the body.*

A fairly heavy load carried, distributed over a tray measuring 21 by 16 inches, was found to require a considerable deviation from the natural posture of the body in order to establish balance with minimal muscular exertion. The same load carried in a tray 12 inches wide produced, of course, a smaller displacement of the centre of gravity. Again, the same load made up of metal within a compass of 12 by 10 by 5 inches, carried slung in an apron with one of the large surfaces resting against the abdomen, allows of a fairly erect carriage. These three variates of the method of adding the load to the front of the body, and compensating for it by a backward tilt of the trunk, may be considered together and their costs compared, in Table XLVII and Fig. XVI.

TABLE XLVII.—*Carrying in Front. Average net values.*

Subject.	Method	Load.	CO_2 per min.	O_2 per min	Cal per min	Hor kgm per min	O_2 per hor. kgm	Grm.-Cals per hor kgm
		lb.						
B	1 W	20	487	609	2·97	5,453	0 112	0·54
		30	585	692	3·41	5,677	0 122	0·60
		40	674	739	3·68	5,856	0 126	0·63
		50	671	755	3·74	5,874	0·128	0·64
B	1*a* N	20	470	520	2·59	5,303	0·098	0·49
		30	504	638	3·10	5,457	0·117	0·57
		40	552	688	3·37	5,647	0 122	0·60
		50	—	—	—	—	—	—
B	1*b* C	20	494	529	2·65	5,263	0·101	0·50
		30	468	571	2 79	5,457	0·105	0·51
		40	544	617	3·05	5,545	0·111	0·55
		50	538	617	3·05	5,717	0 108	0·53
A	1*b* C	20	416	484	2·38	4,620	0·105	0·52
		30	425	500	2·46	4,740	0·106	0 52
		40	407	519	2·52	4,909	0·106	0·51
		50	469	509	2·53	5,029	0·101	0·50

W = Wide tray.
N = Narrow tray.
C = Concentrated load.

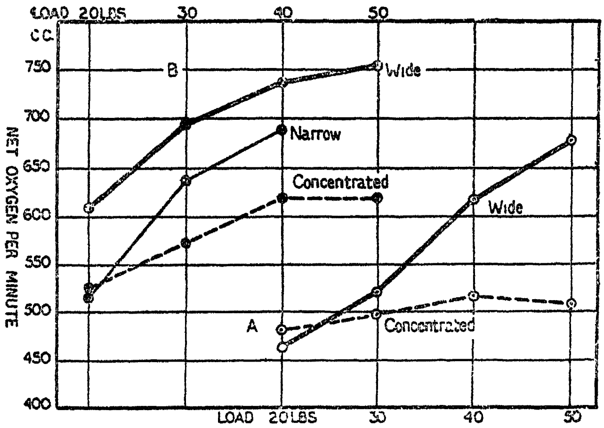

FIG. XVI. Oxygen consumption carrying in tray in front.

B was able with some subjective difficulty and a slight loss of pace to complete the 50 lb. experiment with the broad tray. The figures obtained do not reflect the difficulty experienced, for they are hardly higher than those for 40 lb. It is possible that was a case where the effort was too great for the maintenance this

of the "steady state" so that the measurements do not show the full oxygen requirement of the period samples, although the normal R.Q. does not support this hypothesis It is possible that the low cost is simply due to training.

B preferred to carry the trays at a rather higher level than A had found comfortable—that is, pressed against the epigastric area. B also found it "felt safer" to encircle the tray with the arms, grasping its front corners. Her self-selected posture was therefore slightly different from that found most favourable by A She probably got a freer gait, but a slightly greater proportion of static effort from fixation of the abdominal muscles.

It is curious that though B preferred the narrower box in every way, and though from the figures it is clear that it must have been much less taxing, she failed repeatedly to complete the experimental hour's work with the 50 lbs in the narrow tray so that these data are missing from 1*a*.

The much greater economy of the concentrated method of carrying (1*b* Table XLVII) is confirmation of the idea that the costliness of a mode of carrying depends largely on the degree to which the external load constitutes a force acting downwards *outside* the body's normal base of support.

2. *Carrying on the shoulder.*

Subject A had found that the carrying of loads distributed on a board measuring 36 by 10 inches, balanced on one shoulder, was on the whole a fairly satisfactory and comfortable method of transportation (p 14 of No 29). B confirmed this in her subjective estimates, though the analytical data show a scale of costs both relatively and actually higher than A's. B was not, however, equal to undertaking the carriage of 60 lb. loads, which A had found quite manageable. The flatness of B's cost-curve is again remarkable, as in Table XLVIII and 1*b*. It seems to suggest that the limits of B's carrying powers were imposed more by weakness of muscle, or more particularly of joint, than by any tax in the organism as a whole It is quite possible that with training, she might have shown a capacity and endurance greater than A's, corresponding with the greater metabolic steadiness

TABLE XLVIII.—*Carrying on the Shoulder. Average net values Subject B.*

Load.	CO_2 per min.	O_2 per min.	Cal. per min.	Hor. kgm. per min.	O_2 per hor. kgm	Grm -Cals. per hor kgm.
lb						
20	510	565	2·81	5,596	0·101	0·50
30	561	630	3 12	5,721	0·110	0·55
40	607	633	3·18	5,794	0·109	0·55
50	528	624	3·07	5,735	0·109	0·54

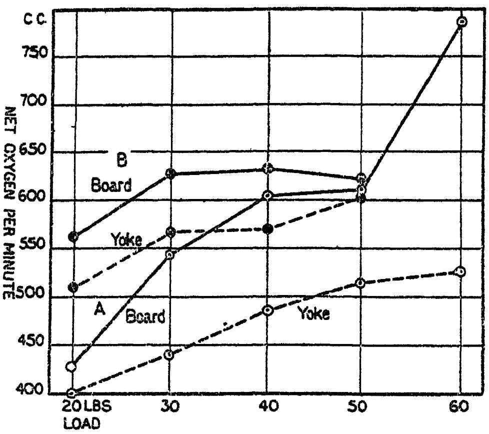

FIG. XVII. Oxygen consumption, carrying on shoulder.

3. *Carrying on the hip.*

The carriage of loads on the hip was found in the previous work to require a quite distinctly greater expenditure of energy than any of the other seven modes of carrying then assessed (p. 15 of No. 29). It was thought that this costliness might be due chiefly to the marked departures from the normal posture and gait, necessitated by the wide tray held horizontally on the hip; while it was clear that there was also local discomfort and some chest-fixation in the heavier loads.

Subject B repeated these experiments under the same conditions as A, and found them disagreeable. She was only able to keep up the work with 50 lb. loads for a very short time, so that data could not be obtained. This incapacity seemed to be related to her arm-length, which is 8 cm. less than A's. The greater lateral inclination of the body demanded by the 50 lb. load seemed to make intolerable the strain on fingers, wrist and elbow which was sufficiently painful at 40 lbs.

In comparing B's values for this carrying with A's (Table XLIX below with Table IX, p. 16 of No. 29) it is seen that B's costs at 40 lbs. were even higher than A's, while it must be presumed that her value for 50 lbs., if measured, would have been higher yet. With the 20 lb. and 30 lb. loads, however, hip-carrying does not in B's case exceed all other modes in costliness; in its place, the wide tray carried in front is found to be most unfavourable with light loads. This disagreement may be due to personal idiosyncrasy in either subject, or to the operation of some chance factor, such as is more apt to affect experiments of an easy character than those which demand a good deal of the subject. But on the whole, it appears from Table XLIX below, that the high costliness of carrying *heavy loads* on the hip is well confirmed by observations on a dissimilar and unbiassed subject.

TABLE XLIX.—*Carrying on Hip. Average net values.*

Subject.	Method	Load	CO_2 per min	O_2 per min.	Cal per min.	Hor kgm. per min	O_2 per hor kgm.	Grm.-Cals. per hor. kgm.
		lb.						
		20	509	592	2·92	5,421	0·109	0·54
B	W	30	537	648	3·17	5,764	0·112	0·55
		40	672	808	3·96	5,757	0·140	0·69
		50	—	—	—	—	—	—
		20	478	559	2 76	5,322	0·105	0·52
B	N	30	571	632	3·12	5,390	0·117	0·58
		40	553	713	3·47	5,560	0·128	0·63
		50	643	831	3·63	5,779	0 144	0·63
		20	450	528	2·73	5,139	0·103	0·52
B	C	30	499	575	2·84	5,282	0·109	0·54
		40	567	617	3·07	5,655	0·109	0·54
		50	581	719	3·51	5,845	0·123	0·60
		20	420	464	2·31	4,473	0·104	0·50
A	N	30	422	493	2·43	4,773	0·103	0·51
		40	547	589	2·94	4,996	0·118	0·59
		50	604	680	3·37	5,106	0·133	0·66
		20	354	422	2·07	4,561	0·093	0·45
A	C	30	367	460	2·24	4,733	0·097	0·47
		40	436	535	2·61	4,886	0·109	0·54
		50	632	675	3·36	5,117	0·132	0·66

W = Wide tray.
N = Narrow tray
C = Concentrated load.

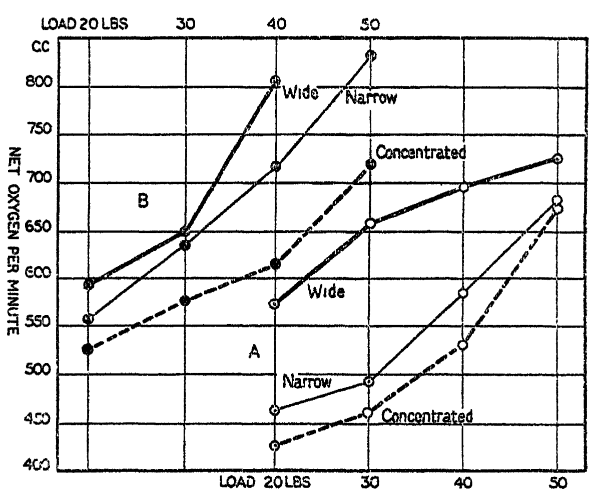

FIG. XVIII. Oxygen consumption, carrying on the hip.

Both subjects repeated the hip-carrying, using a narrower tray, about 12 inches wide, and provided with a hole for the hand grip, which further relieved the uncomfortable finger-flexion required by the broad tray's projecting handle Both A and B found the narrower tray in every way preferable, though B's costs with the 50 lb. load are considerably the highest of any recorded on her.

The narrow tray, like the broad one, was carried approximately horizontally on the hip, the weight being distributed over it. It caused a considerable, though lesser, interference with normal posture and gait. A third set of experiments was therefore devised, with the loads made up in a small box, 12 by 10 by 5 inches, which, resting edge ways on the hip, was carried tucked under the arm, close against the side. It demanded much less curvature of the body than even the narrower tray, and also caused very little disturbance of the free movement of the legs, though the gait must necessarily be unequal when the load is added on one side only of the body. It was not clear that chest-fixation was less with the concentrated load than with the others There was rather an impression that it was greater, owing to the weight resting right against one wall of the chest; but there is only subjective evidence of this

It may be seen from Table XLIX and Fig. XVIII, that in both subjects loads of identical weight were carried on the hip at varying costs, which are obviously related to the degree to which the external load can be approximated to the normal centre of gravity of the body.

4 *Carrying on shoulder-yoke. Subject B.*

In the previous series of experiments, the method of carrying loads suspended from a shoulder yoke was examined, chiefly because of its theoretical interest, as an example of a method which retains the erect posture and free gait of normal walking The yoke is probably very little used in this country, except for small jobs on farms or for carrying water in remote villages, but its advantages are well seen in these uses, and still more clearly, for example, in a country like Norway, where girls thus carry pails of milk down very long and steep mountain paths twice a day throughout the summer. Such an appliance is probably unsuitable for introduction in factories and workshops on the grounds of its width, weight and clumsiness, but it is of interest that the metabolic and other physiological data (Report 29, p. 23) so strongly confirmed the traditional belief in this as the easiest method of all.

The experiments were repeated on the Subject B (see Table L). For her, the costs are rather less strikingly low for this method of carriage than in A's case, but it is evident that again, for this very dissimilar subject, yoke-carrying is, for all loads, the most economical of all the methods tested.

TABLE L.—*Carrying with a Shoulder Yoke Average net values. Subject B.*

Load	CO_2 per min.	O_2 per min	Cal. per min	Hor kgm per min	O_2 per hor kgm	Grm -Cals. per hor kgm
20	442	510	2·52	5,366	0·095	0·47
30	493	570*	2·81	5,560	0·103	0·51
40	492	573*	2·83	5,677	0·101	0 50
50	557	606*	3·02	5,841	0·104	0·52

* *Average* pre-working resting value deducted

Carrying on the yoke is comparable in several ways with the carrying on a board on the shoulder (p 88) In both methods, the weight is borne by the trunk almost without the co-operation of the arms, with concomitant absence of local strains on joints or smaller muscles; in both, there are, in different degree, advantages in chest freedom and unimpeded gait The two methods, therefore, may be compared in Fig. XVII. It is interesting that the retention of the erect posture through the bi-lateral *balancing* of the load, by the use of the yoke, should have so great an effect in promoting physiological economy.

5. *Carrying on the head. Subject A.*

The eighth mode of carriage discussed in Report No. 29 was that of the load upon the head. In these experiments a wide tray was used, the weight being distributed over it. A certain amount of difficulty, however, was experienced in balancing it, a difficulty which was reflected in a high scale of costs. Now, this method, like the last, has theoretical advantages, since the extra weight is added exactly on the long axis of the body, altering the centre of gravity neither laterally nor backwards or forwards. Head carrying, again, is traditional over vast countries where men and women do much of their porterage without animal or mechanical aid, and this habit is in itself, perhaps, presumptive evidence of the physiological suitability of the method. The Subject A, however, being quite inexperienced in such carrying, found that the balancing of heavy loads on a large tray was rather difficult. A more concentrated disposition of the load suggested itself, and the following series of experiments was carried out under the same conditions, and without further practice in the interim. The load, made up in iron blocks, was contained in a box 12 by 10 by 5 inches, and was balanced on the head without difficulty. The only adverse circumstances involved were, with heavy loads, a small degree of strain in the muscles of the neck, which had to be held very rigid; and a slight chest-fixation, perhaps partly nervous in origin, due, that is, to over-care in maintaining steady balance. Table LI and its graph show the much greater efficiency of the more concentrated load

TABLE LI.—*Carrying on the Head—Concentrated Load. Average net values. Subject A.*

Load	CO_2 per min.	O_2 per min.	Cal. per min.	Hor. kgm. per min.	O_2 per hor. kgm.	Grm -Cals. per hor kgm
20	342	459	2·22	4,671	0·098	0·47
30	429	491	2·43	4,813	0·102	0·50
40	478	577	2·83	4,908	0·118	0·58
50	505	590	2·91	5,073	0·116	0·57

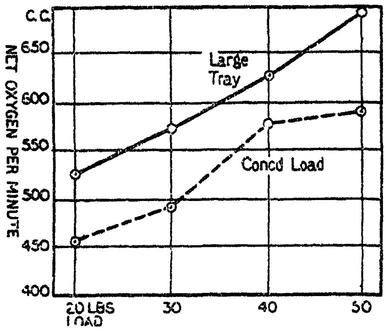

FIG. XIX. Oxygen consumption, carrying on the head

COMPARISON OF FINDINGS, AND GENERAL CONCLUSIONS.

Table LII and Fig. XXV show the comparative costs of the various modes of carriage in the subject B. The yoke is the most economical method, the apron next best, while the shoulder and the *concentrated* load on the hip are also moderate in cost B's curves, on the whole, are flatter than A's, showing an abrupt rise of costs between the 40 lb. and 50 lb. loads in the hip-carrying methods only.

TABLE LII.—*Decreasing Costs (c.c. Oxygen per hor. kgm.). Net values. Subject B.*

20 lb.		30 lb.		40 lb		50 lb.	
Method.	Cost.	Method.	Cost	Method.	Cost.	Method.	Cost
Front, wide ..	0·112	Front, wide .	0·122	Hip, wide ..	0 140	Hip, wide	—
Hip, wide ..	0·109	Front, narrow	0 117	Hip, narrow ..	0 128	Front, narrow	—
Hip, narrow .	0·105	Hip, narrow ..	0·117	Front, wide ..	0·126	Hip, narrow	0 144
Hip, conc. ..	0·103	Hip, wide ..	0 112	Front, narrow	0·117	Front, wide .	0 128
Shoulder ..	0·101	Shoulder ..	0 110	Front, conc ..	0·111	Hip, conc. .	0·123
Front, conc. ..	0·101	Hip, conc. ..	0·109	Hip, conc. ..	0·109	Shoulder .	0 109
Front, narrow	0·098	Front, conc. ..	0 105	Shoulder ..	0·109	Front, conc. ..	0 108
Yoke	0·095	Yoke	0·103	Yoke	0·101	Yoke .. .	0 104

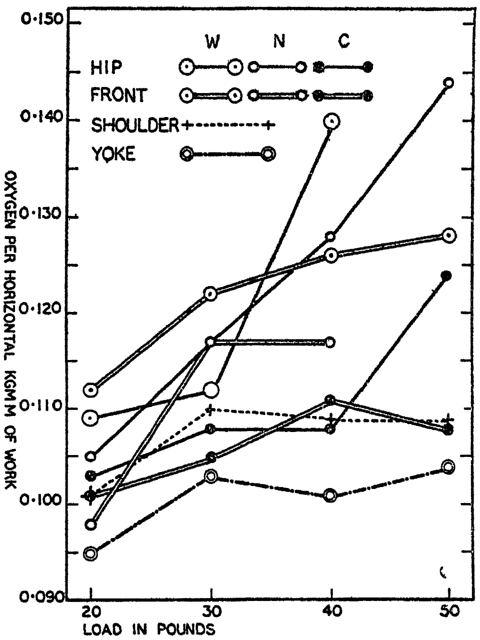

FIG. XX. Comparative oxygen consumption per horizontal kilogramme meter of work, for various methods of carrying and various loads (W=wide tray; N=narrow tray; C=concentrated load).

The foregoing experiments, as a whole, appear to confirm the previous findings, that the metabolic costs of human porterage are relative to the disposition of the load, and that the favourable and unfavourable circumstances of the many possible ways of carrying can be analysed into four distinguishable but often inseparable factors. Thus, it certainly appears that such a disposition of the load as involves any considerable departure from the erect *posture*, especially when, as is almost always the case, the abnormal posture is combined with a necessary abnormality of *gait*, inevitably results in a relatively high physiological cost. Any tendency of a mode of porterage to require the thoracico-abdominal type of static effort is always costly, and will probably cause special strain on the poorly-developed or untrained worker. When heavy loads are carried by methods involving strain of the joints and smaller muscle groups, the question of local capacity, development of the arms in particular, is, of course, of great importance. A severe strain on feeble joints or muscles leads to ill-coordinated relief by other muscle groups, and in extreme cases to a struggle involving the greater part of the muscular system, with necessarily very high metabolic costs. Yet a subject with poorly-developed arms may be able to carry with ease on the shoulder, and it is manifest that the matter of *local comfort* has much to do with the individual worker, and with her capacity for continuous effective labour.

In these experiments, the limit of capacity was about reached in the 50 lb. load in the broad tray, both carried on the hip and in front; and for the subject B, 40 lb. in the broad tray and 50 lb. in the narrow tray on the hip were also highly taxing. Otherwise, it is not considered that either subject at all approached a condition of such marked local or general distress as to lead to serious inco-ordination. Even in those modes of carriage when the 40, 50 or 60 lb. load involved a cost exceeding the high figure of 0·140 gram cals. per horizontal kilogrammetre, there was no appreciable breathlessness—indeed, it is of course necessary to abandon any experiment in which marked dyspnoea supervenes, as accurate assessment by the Douglas bag method is very difficult, if not indeed impossible, to achieve in such circumstances. The inference, as far as any can be drawn from these experiments, is again that 50 lb. for "well-disposed" loads, and 40 lb. for "ill-disposed" loads is likely to be about the highest economic load for women.

The question of thoracico-abdominal effort plays a less important rôle in the cost of carrying than it does in more severe and abrupt exertions, such as lifting a weight. It would seem, therefore, that in planning for physiological economy where it is necessary for women to do much semi-continuous porterage of considerable loads, it would be enough to give attention to the preservation of normal posture and gait, as far as may be. The other favourable conditions of chest freedom and absence of severe local discomforts will be found to be incidental to the more satisfactory postures.

Effect of Carriage of Loads on Pulse and Blood Pressure.

In the following experiments, a study was made of the reactions of the circulatory mechanism to the various modes of carriage, with loads from 20 to 50 lb., by recording the pulse-rate and blood-pressure at half-minute intervals during the five minutes immediately after the cessation of work. As the collection of such data had been found unsatisfactory in the metabolic experiments, where the load was carried in alternate circuits of a 100 yards corridor, a different method was adopted in the present instance. The subject was required to walk on a moving platform, carrying the load continuously, at the same pace as that used in the metabolic experiments, the motor being adjusted to give exactly this speed, whatever the load As the subject always remained on the same place, it was hoped that pulse counts and pressure determinations might be made during the actual performance of the work, but this proved impossible, owing to the movements of walking and the noise of the motor. The "stationary" walking, however, allowed the apparatus to be close at hand, and the large Tycos sphygomanometer to be connected continuously with the arm of the subject. Thus there was no difficulty in obtaining the first determination of blood-pressure at the 15th second, by stopwatch, from the stopping of the motor.

The continuous carrying of a load is, of course, much more strenuous than the intermittent work of the metabolic experiments, which was 73 seconds with the load alternating with 73 seconds walking unloaded ; and when the continuous work is done upon the platform, the difficulty is increased because it is necessary for the subject to walk perfectly evenly and accurately throughout. Those slight, almost instantaneous pauses on a step, to effect some small shift of balance or to relieve a local strain, which are unconsciously made when one walks in the ordinary way with a heavy load for a considerable distance, should not, and sometimes cannot, be made at all when walking on the platform, because they entail so considerable a change of balance as to alter the gait during the next two or three steps at least. It is a case where the human body must subserve the rhythm of the machine, or pay for its failure This being so, it was necessary to limit the duration of the carrying to a period short enough to be compassed under the worst conditions—that is, when the 50 lb load had to be carried by a method involving severe local strain or other disability. It was found by trial that five minutes was quite as long as the subject could keep up without relief in such circumstances, and the short period of five minutes had therefore to be taken throughout as the working period The very great reduction in endurance which follows the cutting out of the alternating unloaded walk—which is, of course, merely a form of the familiar rest-pause—is rather striking. It would be possible to make some interesting numerical assessments of the differences between continuous and intermittent load-carrying both in metabolic costs and in circulatory reactions, by such a platform method, since a high table straddled across the moving belt makes accurately-timed lifting and lowering of the load quite easy for the subject—easy, that is, for some but not for all the modes of carriage ; for no ordinary woman can lift a 50 lb load on and off her head unaided and without breaking step.

The period of five minutes of continuous work, though it may seem both too short and too strenuous to be at all representative of women's industrial conditions, affords as a matter of fact a very good standard test for such phenomena as it was desired to record here, and corresponds fairly well to tests used in very many physiological and pathological investigations of heart reactions. The findings of the present experiments must, however, be looked upon as a separate study, giving values comparable within themselves, but not the counterparts of the metabolic values previously reported, nor pretending to represent the actual magnitudes of the demands on circulatory accommodation made by similar work on the women in factories.

Experimental procedure.

The experiments were carried out as follows .—First, basal values were obtained after ten minutes lying at rest. These basal values are practically identical throughout, the experiment

being abandoned on occasions when, for any reason guessed or unknown, the subject did not show her normal resting levels of 102 for blood-pressure, 76 for pulse.

Secondly, determinations were made of the pressure and pulse with the subject standing at ease before work began. The results here are less steady, the reactions of the change of posture having apparently not fully subsided in a good many instances. As it believed that this was often due merely to irregularity in timing the observations, the figures representing this base-line (averages 112 and 83) have not been used in computing the results of the work determinations.

A third base level was obtained by taking the pulse-rate and blood-pressure 15 seconds after the finish of a period of five minutes' walking, unloaded, at the experimental pace. These figures should provide a corrective for the subsequent work data, since they should reflect any peculiarity of the day's reactions due to weather conditions or other uncontrollable factors. The recovery of the pulse and pressure in the five minutes following the cessation of the work are therefore expressed as rises above and falls below the base-line of the " walking " pulse and pressure.

The large Tycos sphygomanometer was used, its accuracy being checked by a mercury manometer. A phonendoscope held in place by a spring band just below the bend of the elbow was found to give much more reliable results than palpation at the wrist.

The experimental data are presented in the order of the methods of carriage as discussed in Report No. 29. The observations were actually carried out in haphazard succession, to avoid special training as far as possible. The four replica experiments from which the averages are drawn, were, however, made on the same day in the majority of cases, to spread out the effect of any possible fatigue. It is clear that it is fairer that any slight after-effect of fatigue from, say, the 50 lb. head load, which might survive a reasonably long rest-pause, should affect a further observation of exactly the same sort than that it should modify the reactions to some other mode or load.

The determinations of blood pressure were made by a practised observer, at the 15th and 45th seconds after switching off the motor, and half-minute intervals thereafter, for five minutes. The pulse was counted by the subject herself from the 5th to the 20th second, from the 30th to 45th, and thereafter from 0 to 15, and 30 to 45 seconds of each minute.

Results.

The values represented below are the averages of four experiments on each load for every mode of carriage.

It was only possible to carry out these observations on the one subject, A.

TABLE LIII—*Average curve of recovery. Mode I. Carrying in broad tray in front. Base-line walking.* *

* Figures given in Table LIII to LXIII are, in the case of blood pressure, the number of mm above or below the base line value. i.e. value for walking, and in the case of pulse. beats per min. above or below the same levels Figs. XXI to XXXI give these same values in graphic form.

	Load (lb.)	Half-minute periods after completion of work										Average Deviation
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
Pressure.	50	+24 5	+20 0	+13 66	+ 3 66	+ 0 33	− 1 5	− 3 16	− 4 33	− 5 33	− 6 5	5 2
	40	+19·25	+19·0	+15 5	+ 8 0	+ 3 0	+ 1·5	− 1 5	− 2 5	− 5·5	− 6 0	2 7
	30	+19 4	+15·4	+ 9 8	+ 1 8	− 7·25	− 6 2	− 7 4	− 7 4	—	—	5·1
	20	+ 6 75	− 0 5	− 4 5	− 6 25	− 7 25	− 8 5	−10 0	− 9 5	− 9 25	− 9 0	2·9
Pulse.	50	+34 33	+14 66	+ 4·66	+ 3 33	+ 2 33	+ 1 66	+ 1 66	+ 4 33	− 0 33	+ 3 33	5 8
	40	+32·0	+22 5	+13 5	+11 0	+10 0	+ 6 5	+ 7 5	+ 8 5	+ 8 5	+ 7 0	5 4
	30	+22·0	+11 6	+ 3 6	+ 4 4	+ 6·8	+ 6 0	+ 2 8	+ 4 5	—	—	4 0
	20	+ 9·0	+ 1 0	− 2 5	− 1 5	+ 1·5	+ 2 0	+ 1 0	+ 1·5	0 0	+ 0 5	3 3

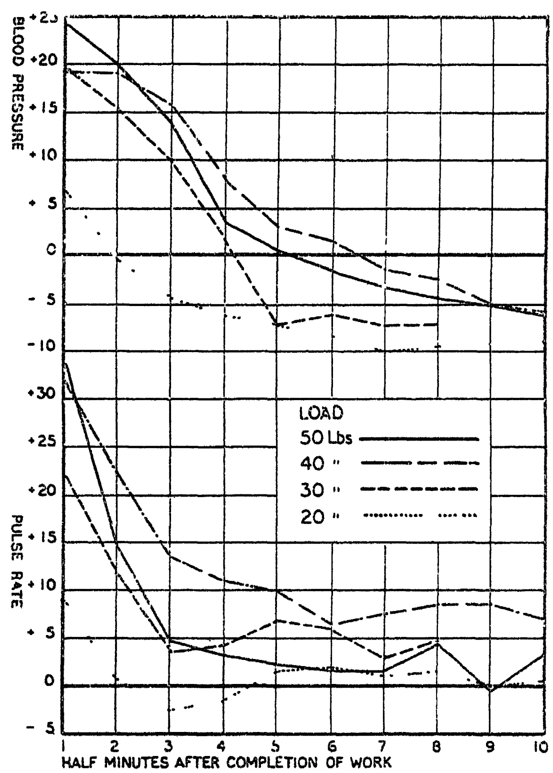

FIG XXI. Rate of recovery of blood pressure (in mm. Hg) and pulse rate per minute, after carrying load in broad tray in front.

The carrying of loads of 50 and even 40 lb. in the broad tray is a little fatiguing on the moving platform, chiefly because of the shortened stride (noted on p. 11 of Report No. 29), which makes

accurate and evenly balanced walking more difficult. It may be noticed from the table or more readily from the graph, that the effect seems to be larger on the pulse-rate than on the pressure.

The sharp fall and small secondary rise of the pulse-rate may also be noted, they are common phenomena of the recovery from work

TABLE LIV —*Average curve of recovery Mode Ib. Carrying in apron in front Base-line walking.*

	Load (lb.)	Half-minute periods after completion of work										Average Deviation
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
Pressure.	50	+15 2	+11 4	− 1 4	− 5·2	− 9 2	−10 0	− 6 6	− 7 6	− 9 2	−11 8	4 6
	40	+23 0	+13 0	+ 8 0	+ 3 5	+ 0 5	+ 1 0	− 1 5	− 3·0	− 6 0	− 5 0	4 1
	30	+ 7·75	+ 1·25	− 5 5	− 9 5	−12 75	−15 0	−16 6	−17 0	−15 75	−15 75	2 9
	20	+17·5	+16·0	+ 5 0	+ 1 5	+ 1 5	− 1 5	− 1 5	− 2 5	− 4 0	− 5·0	3 0
Pulse	50	+26·0	+17 2	+ 8 8	+10 8	+ 3 2	+ 7 2	+ 4 0	+ 8 4	+ 4 8	+ 5 2	7 3
	40	+16 0	+ 6 5	+ 4 0	+ 3 5	+ 2 0	+ 7 0	+ 6 0	+ 8 0	+ 4·5	+ 7 5	4 5
	30	+14 5	+ 5 0	− 5 0	+ 1 0	− 0 5	+ 0 25	− 1 0	− 0·5	+ 2 5	+ 2 0	2 9
	20	+ 8 5	+ 1 0	−11·0	− 4 5	− 6 0	− 5 0	− 7 0	− 4·5	− 8 5	− 6·5	3·2

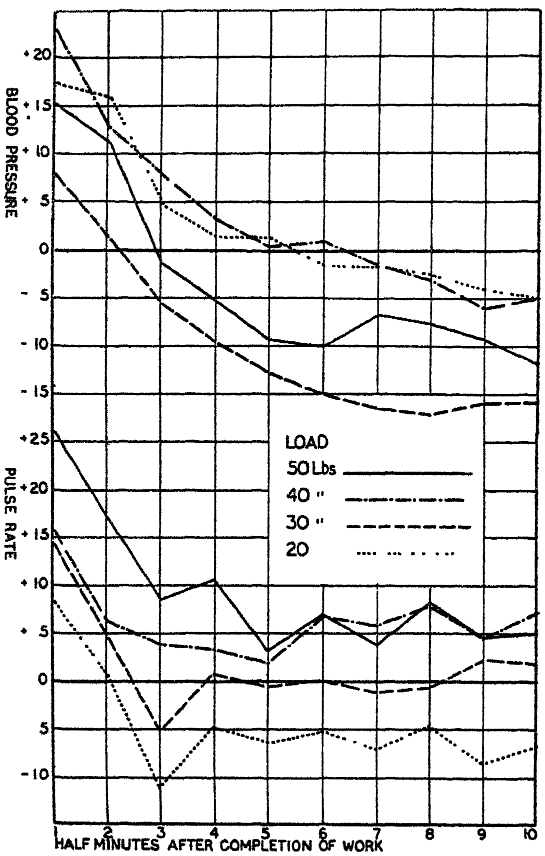

FIG. XXII. Rate of recovery of blood pressure (in mm. Hg.) and pulse rate per minute, after carrying load in apron in front.

The variation of Mode I with a narrow tray (I*a*) was not tested for this subject on the walking-platform. The carrying of a concentrated load, slung in an apron, close against the abdomen, is found, on the whole, to cause a smaller rise and a more rapid recovery than the wide tray. This is better seen in the pulse-rates, for the blood-pressures in this series are anomalous, those for 40 lb. and 20 lb. being certainly too high. This is due to a number of unusually low readings for the walking base-line, not to high gross values for the post-work determinations

TABLE LV.—*Average curve of recovery. Mode III. Carrying in two pails in hands. Base-line walking*

	Load (lb.)	Half-minute periods after completion of work.										Average Deviation
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
Pressure	50	+22 75	+24 0	+21 25	+15 75	+ 8 5	+ 4 75	+ 1 75	+ 0 25	− 1 25	− 1·75	1 5
	40	+13 0	+11 25	+ 7 25	0	− 2 5	− 7 5	− 8 5	−11 5	− 7 5	−11·5	3 0
	30	+ 6 25	+ 4 5	− 0 75	− 2 0	− 4 75	− 6 75	− 7 0	− 5 75	− 8 75	−10 0	5 5
	20	+ 7 5	+ 6 0	− 4 0	− 4 5	− 6 5	− 6·5	− 5 5	− 7 0	− 7 5	− 8 0	2 5
Pulse.	50	+45 0	+32 5	+12 0	+ 9 0	+10 0	+10 0	+ 8 0	+ 9 0	+ 9 0	+10 0	3 1
	40	+36 5	+21 5	+ 9 0	+ 5 5	+ 6 0	+ 7 5	+ 2 5	+ 4 5	+ 5 5	+ 4 5	2 6
	30	+18 25	+10 75	+ 1 75	+ 2 5	+ 4 0	+ 4 5	+ 3 5	+ 5 0	+ 3 0	+'4 0	2 7
	20	+14·0	+ 4·5	− 1 5	0	+ 0 5	+ 2·5	+ 2 0	0	− 1 0	+ 1 0	3 1

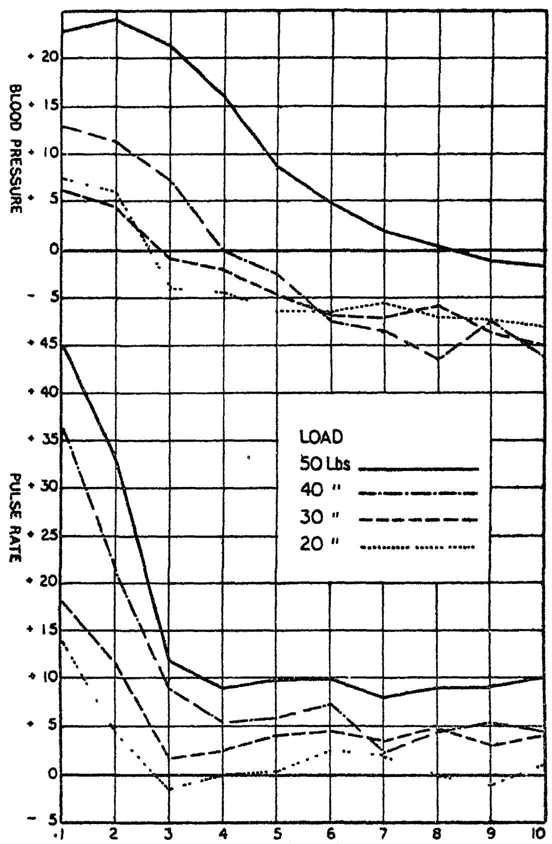

FIG. XXIII. Rate of recovery of blood pressure (in mm Hg.) and pulse rate per minute, after carrying load in pails at side.

TABLE LVII.—*Average curve of recovery. Mode V. Carrying on the hip—broad tray. Base-line walking.*

	Load (lb)	Half-minute periods after completion of work.										Average Deviation
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
Pressure.	50	+24·33	+22 5	+20 33	+10 66	+ 5·0	+ 3·0	+ 0 5	− 1·16	− 2 66	− 4·33	3 7
	40	+22 75	+17·75	+ 5·75	− 0·5	− 6·5	− 9·0	−10·25	−10·75	−11 25	−11 25	2·9
	30	+16 0	+ 8 0	+ 5 0	− 3 0	− 1 5	− 4 5	− 4 5	− 9·0	− 6 5	− 6 0	5 6
	20	+ 9·33	+ 3·33	+ 1·5	− 3·0	− 7 0	−10 5	−11 0	− 8 5	− 8 5	−12·0	4 1
Pulse.	50	+36·66	+14 0	+ 1·33	+ 1·43	+ 2·0	+ 2 66	+ 1 66	+ 3 33	+ 1·0	+ 3 0	6 6
	40	+31 0	+19 0	+ 5 5	+ 8 5	+ 1·5	+ 6 0	+ 5 5	+ 8 0	+ 5 0	+ 5 5	3·5
	30	+12·0	+ 3·5	+ 1·0	0	+ 0 5	− 1 5	− 1·0	− 3 5	− 1·5	− 6 5	5·5
	20	+11 5	+ 6 0	− 0·5	− 1 0	+ 4·5	+ 5 5	+ 6 0	+ 5 0	+ 0 5	+ 2 0	5 1

Carrying 50 lb. was found taxing, on account of the strain on the fingers. The difficulty of gait was much less than with the same load on the shoulder, herein differing from the conditions of ordinary carrying.

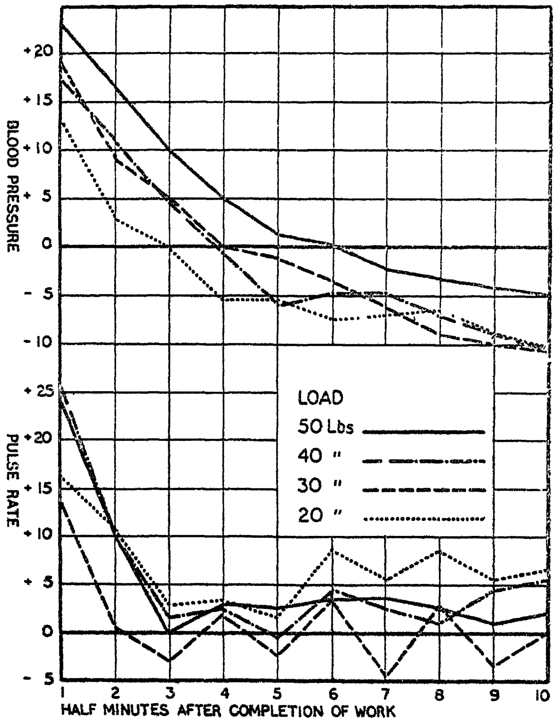

FIG. XXVI. Rate of recovery of blood pressure (in mm. Hg.) and pulse rate per minute, after carrying load in narrow box on hip.

TABLE LVIII.—*Average curve of recovery. Mode Va. Carrying in narrow tray on hip. Base-line walking.*

	Load (lb)	Half-minute periods after completion of work										Average Deviation.
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
Pressure.	50	+23 0	+16·5	+10 0	+ 5 0	+ 1 25	+ 0 25	− 2 25	− 3 25	− 4 25	− 5 0	2 7
	40	+17 25	+11·0	+ 4 5	− 0 75	− 6 0	− 4 75	− 4 75	− 7 0	− 9 0	−10 75	7 3
	30	+19 0	+ 9 0	+ 5 0	0	− 1 0	− 3·5	− 6·0	− 9 0	−10 0	−11 0	2·2
	20	+13 0	+ 3 0	0	− 5 5	− 5 5	− 7 5	− 7 0	− 6 5	− 9 0	−10 5	4 5
Pulse.	50	+24 0	+10 0	0	+ 3 0	+ 2 5	+ 3 5	+ 3 5	+ 2 5	+ 1 0	+ 2 0	5 4
	40	+25 5	+10 0	+ 1 5	+ 2 5	− 0 5	+ 4 5	+ 2 5	+ 1 0	+ 4 5	+ 5 5	4 0
	30	+13 5	+ 0 5	− 3 0	+ 2 0	− 2 5	+ 3 5	− 4 5	+ 2 5	− 3 5	0	3 0
	20	+16 0	+10·5	+ 3 0	+ 3 5	+ 1 5	+ 8 8	+ 6 5	+ 8 5	+ 5 5	+ 6 5	4 6

These show on the whole a less degree of disturbance than was caused by the broad tray, but the difference is only considerable in the 40 and 50 lb. loads, where the relief from the more severe local strain was much appreciated. The peculiar oscillation of the pulse-rate after the 30 lb load is unexplained.

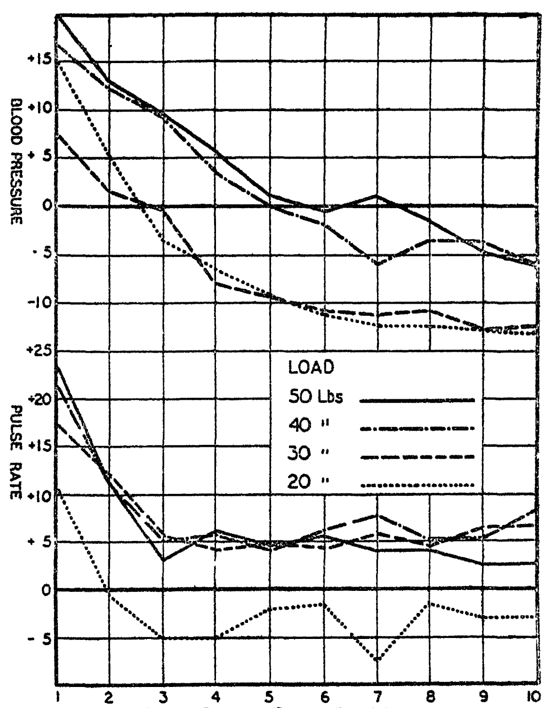

FIG. XXVII. Rate of recovery of blood pressure (in mm. Hg) and pulse rate per minute, after carrying load concentrated on hip.

TABLE LIX.—*Average curve of recovery. Mode Vb. Carrying a concentrated load on the hip. Base-line walking.*

	Load. (lb)	Half-minute periods after completion of work.										Average Deviation.
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
Pressure.	50	+20 0	+13 0	+ 9 5	+ 5·5	+ 1 0	− 0 5	+ 1 0	− 1 5	− 5·0	− 6 5	6·4
	40	+16·5	+12 0	+ 9 0	+ 3 5	0	− 2·0	− 6 25	− 4 0	− 4·0	− 6 5	2 3
	30	+ 7·25	+ 1 5	− 0 33	− 8·0	− 9 5	−10 75	−11·25	−11 0	−13 0	−12 0	4·1
	20	+15·0	+ 5 25	− 3·5	− 6·5	− 9 25	−11 0	−12 5	−12 5	−13 0	−13 25	3·5
Pulse.	50	+23 0	+11·0	+ 3·0	+ 6 0	+ 4 5	+ 5 5	+ 4 5	+ 4 0	+ 2·5	+ 2·5	3·7
	40	+21 0	+11 0	+ 5·0	+ 5 5	+ 4 0	+ 6·0	+ 7 5	+ 5 0	+ 5·0	+ 8·0	4·3
	30	+17·0	+11·5	+ 5·5	+ 4·25	+ 5 0	+ 4·5	+ 6·0	+ 4 5	+ 6 5	+ 6·7	4 9
	20	+10 5	− 0 5	− 5·0	− 5 0	− 2 0	− 1·5	− 7·5	− 1 5	− 3 0	− 3 0	3 1

The reaction caused by the concentrated load is not appreciably less, it seems, than that for the narrow box, though the comfort of carrying it is considerably greater, and the metabolic costs have been shown to be lower. Perhaps we have here some evidence that the tucking of a weighty load under the arm does induce a certain amount of special chest-fixation, as surmised from subjective symptoms in the metabolic work.

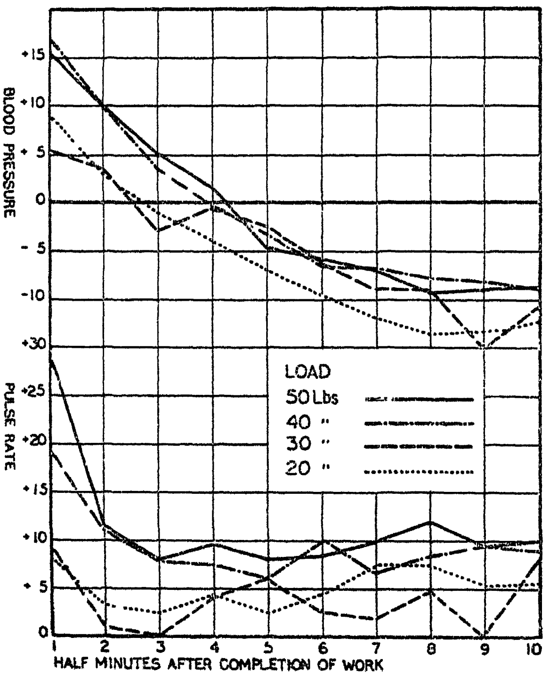

FIG. XXVIII. Rate of recovery of blood pressure (in mm. Hg.) and pulse rate per minute, after carrying load on back.

TABLE LX.—*Average curve of recovery. Mode VI. Carrying in rucksack. Base-line walking.*

	Load (lb)	Half-minute periods after completion of work										Average Deviation
		(1)	(2)	(3)	(4)	(5)	(6	(7)	(8)	(9)	(10)	
Pressure.	50	+15 3	+ 9 8	+ 5·0	+ 1·5	− 4 8	− 5 8	− 7·0	− 9 3	− 9 0	− 8·8	2·1
	40	+16·8	+ 9·8	+ 3 5	− 0·3	− 3 3	− 6 8	− 6 8	− 7 8	− 8 3	− 9·0	3 0
	30	+ 5·5	+ 3 5	− 3 0	− 0·5	− 2·5	− 6 5	− 9 0	− 9 0	−15 0	−11 0	4·8
	20	+ 9 0	+ 3 0	− 1 0	− 4 0	− 7·0	− 9 5	−12·0	−13 5	−13 3	−12 3	1·7
Pulse.	50	+28·5	+12 5	+ 8·0	+ 9 5	+ 8 0	+ 8 5	+10·0	+12 0	+ 9 5	+10·0	4 1
	40	+19 0	+11·5	+ 8 0	+ 7·5	+ 6·0	+10 0	+ 6·5	+ 8 5	+ 9·5	+ 9 0	4 5
	30	+ 9 0	+ 1 0	0	+ 4 0	+ 6 0	+ 2 5	+ 2 0	+ 4 8	0	+ 8 0	3 5
	20	+ 8 0	+ 3 3	+ 2 5	+ 4 5	+ 2 5	+ 4 5	+ 7 5	+ 7 5	+ 5·5	+ 5 5	2 5

Rucksack carrying appears to cause considerable disturbance of the pulse-rate only at 50 lb., while the pressure reactions are moderate throughout. This method of carrying is found particularly easy on the platform, as there is no interference with leg movements, nor is the body inclined to one side or the other—a point of some importance for accurate steering on a two-foot-six running belt.

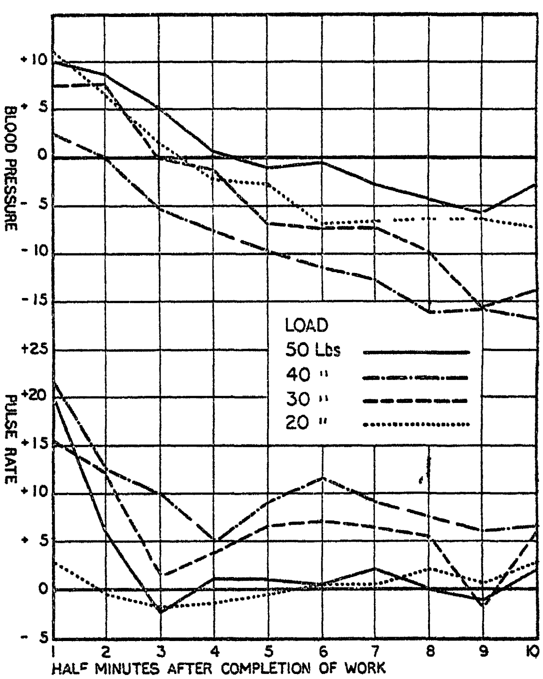

FIG. XXIX. Rate of recovery of blood pressure (in mm. Hg.) and pulse rate per minute, after carrying load in yoke.

TABLE LXI.—*Average curve of recovery. Mode VII. Carrying on a yoke. Base-line walking.*

	Load (lb)	Half-minute periods after condition of work										Average Deviation.
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
Pressure	50	+10 0	+ 8 5	+ 5 0	+ 0 5	− 1 0	− 0 5	− 3 0	− 4 5	− 6 0	− 3·0	4·6
	40	+ 2 5	0	− 5 5	− 7 8	− 9 8	−11 5	−12 8	−16 3	−16 0	−17 0	5 0
	30	+ 7·5	+ 7 5	0	− 1 5	− 7 0	− 7 5	− 7 5	−10·0	−16·0	−14·0	3 9
	20	+11 0	+ 6 5	+ 1 5	− 2 3	− 2 8	− 7 0	− 6 8	− 6 5	− 6 5	− 7 3	1 9
Pulse	50	+20 0	+ 6 0	− 2 5	+ 1 0	+ 1 0	+ 0 5	+ 2 0	0	− 1 0	+ 2 0	5 8
	40	+21 5	+12 5	+10·0	+ 5 0	+ 9 0	+11·5	+ 9 0	+ 7 5	+ 6 0	+ 6 5	3 7
	30	+15·5	+12·0	+ 1·5	+ 3 75	+ 6 5	+ 7 0	+ 6 5	+ 5 5	− 2 0	+ 6 0	3 8
	20	+ 3·0	− 0 5	− 2 0	− 1 5	− 0 5	+ 0 5	+ 0 5	+ 2 0	+ 0 5	+ 2 7	4 1

Yoke-carrying is no less easy on the platform than on terra firma, and the ease is reflected in the small magnitude of the increments of blood-pressure and pulse-rate, which, however, are less conspicuously low in comparison with those recorded in other modes than are the metabolic costs. The correspondence between circulatory reaction and energy expenditure is a general one, but not an invariable one.

TABLE LXII.—*Average curve of recovery. Mode VIIIa. Carrying concentrated load on the head. Base-line walking.*

	Load. (lb.)	Half-minute periods after completion of work										Average Deviation.
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
Pressure	50	+30 4	+30 2	+27 4	+21 8	+14 6	+ 9 2	+ 4 8	+ 2 2	+ 0 6	+ 0 6	6·5
	40	+18 0	+12 5	+ 8·8	+ 4 5	+ 1 3	− 0·3	− 2 8	− 4 3	− 5 0	− 6·0	3 3
	30	+ 8 0	+ 5 0	− 0·3	− 6·0	− 8 5	−11 0	−13 5	−14 8	−14 0	−13 3	2 8
	20	+10 5	+ 5 5	+ 2 0	+ 0 25	− 4·0	− 6 8	− 7 5	− 9 0	−10 5	−11 8	1·6
Pulse.	50	+54 0	+28·0	+12 8	+ 9 2	+ 6 0	+ 4 8	+ 2 4	+ 3 2	+ 3 2	+ 2 0	5 4
	40	+28 0	+16·0	+ 4·5	+ 3 0	+ 5 0	+ 6 0	+ 6 0	+ 6 5	+ 7·0	+ 5·0	2·9
	30	+23·5	+10·5	+ 0 5	+ 1 5	+ 2 5	+ 1 5	+ 2 0	+ 2·3	+ 1 5	+ 2 7	3 1
	20	+14·0	+ 7 0	+ 5·0	+ 5 0	+ 2 5	+ 6 0	+ 7 5	+ 4·5	+ 1 0	0	4 1

The pulse-rate immediately after carrying the 50 lb. load on the head were among the highest ever recorded on this subject (164 per min. on one occasion, 147 per min. on the average). The method was extremely exacting for heavy loads, because of the great accuracy of walking required, since recovery from a false step would have been impossible without overbalancing the load. The machine here greatly exaggerates the difficulties and the subject could not have undertaken to carry the 40 or 50 lb. loads on the broad tray, as was done without undue strain in the metabolic experiments (see p. 19 of Report No. 29).

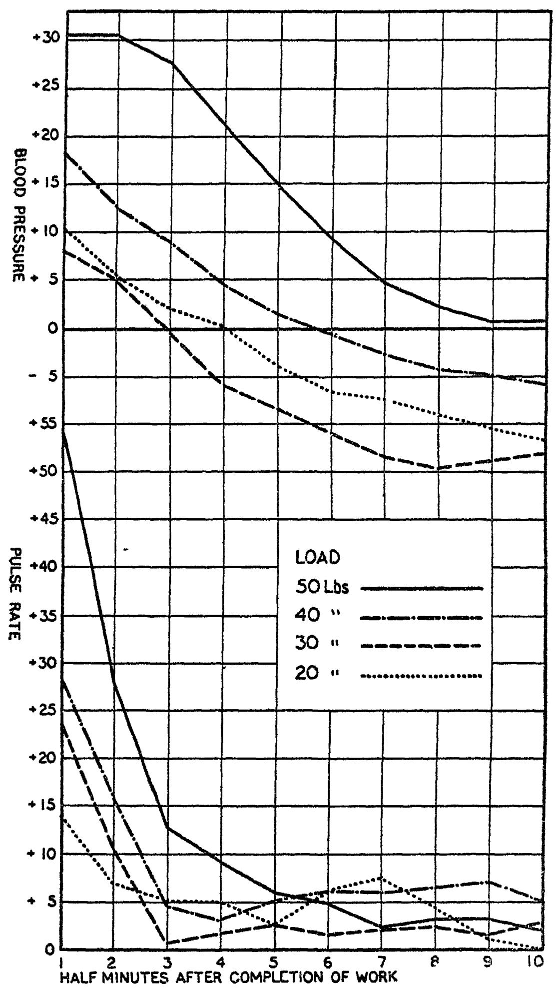

FIG XXX. Rate of recovery of blood pressure (in mm. Hg) and pulse rate per minute, after carrying load on head.

TABLE LXIII.—*Average curve of recovery. Averages of all methods of carrying. Base-line walking.*

	Load. (lb)	Half-minute periods after completion of work.									
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Pressure.	50	+21·4	+18·3	+13·5	+ 7·4	+ 2·4	+ 0·2	− 1·4	− 3·2	− 4·5	− 5·3
	40	+16·6	+11·9	+ 6·5	+ 1·4	− 2·2	− 4·3	− 6·0	− 7·3	− 7·9	− 9·1
	30	+10·7	+ 6·3	+ 1·0	− 3·0	− 5·8	− 7·8	− 9·1	−10·1	−12·1	−11·5
	20	+10·8	+ 5·5	+ 0·4	− 2·8	− 4·8	− 7·1	− 7·7	− 8·0	− 8·8	− 9·7
Pulse	50	+34·0	+17·9	+ 6·2	+ 6·4	+ 4·7	+ 5·1	+ 4·0	+ 5·2	+ 3·5	+ 4·5
	40	+26·0	+15·4	+ 7·1	+ 5·9	+ 4·9	+ 7·2	+ 6·0	+ 6·4	+ 6·1	+ 6·5
	30	+16·2	+ 6·6	+ 8·4	+ 2·5	+ 3·1	+ 3·4	+ 1·5	+ 2·6	+ 0·8	+ 3·3
	20	+10·5	+ 3·9	− 0·9	− 0·7	+ 0·5	+ 2·7	+ 2·2	+ 2·9	+ 0·6	+ 1·5

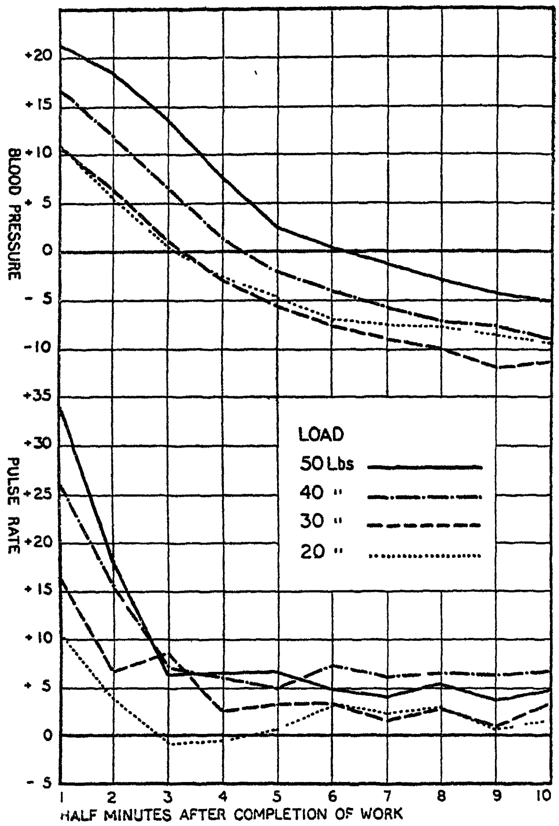

FIG. XXXI. Average recovery rates for all methods.

When all experiments on each load are summed, the average curves are as shown in Fig. XXXI. They show that the reaction of both pressure and pulse varies directly with the amount of external work performed, but no exact proportional relation can be found.

TABLE LXIV.—*Maximum blood pressure and pulse rate recorded at 15 seconds after stop. Increase over walking level.*

	50 lb.		40 lb		30 lb.		20 lb	
	Method	Increase	Method.	Increase	Method.	Increase	Method	Increase
Blood Pressure.	Head	30 4	Apron	23 0	Front, wide	19 4	Apron ..	17 0
	Shoulder .	28 5	Hip, wide ..	22·8	Hip, narrow	19 0	Hip, conc	15 0
	Front, wide	24 5	Front, wide	19 3	Hip, wide .	16·0	Hip, narrow	13 0
	Hip, wide	24 3	Head ..	18 0	Shoulder .	10 0	Yoke .	11 0
	Hip, narrow	23 0	Hip, narrow	17 3	Head	8 0	Head ..	10 5
	Pails .	22 8	Shoulder }	16 8	Apron ..	7 8	Shoulder .	9 5
	Hip, conc.	20·0	Rucksack }		Yoke	7 5	Hip, wide ..	9·3
	Rucksack .	15 3	Hip, conc	16 5	Hip, conc	7 3	Rucksack ..	9·0
	Apron ..	15 2	Pails	13 0	Pails .	6·3	Pails	7 5
	Yoke .	10 0	Yoke .	2 5	Rucksack	5 5	Front, wide	6 8
Pulse.	Shoulder ..	54·5	Pails ..	36 5	Head .	23 5	Hip, narrow	16 0
	Head .	54 0	Front, wide	32·0	Front, wide	22 0	Head }	14·0
	Pails ..	45 0	Shoulder	31 5	Pails ..	18 3	Pails }	
	Front, wide	34 3	Hip, wide .	31·0	Shoulder }	17 0	Hip, wide ..	11·5
	Hip, wide ..	30·6	Head .	28 0	Hip, conc }		Hip, conc ..	10 5
	Rucksack	28·5	Hip, narrow	25·5	Yoke .	15 5	Shoulder .	10·0
	Apron ..	26 0	Yoke ..	21 5	Apron .	14·5	Front, wide	9 0
	Hip, narrow	24·0	Hip, conc ..	21·0	Hip, narrow	13 5	Apron ..	8 5
	Hip, conc...	23·0	Rucksack .	19 0	Hip, wide ..	12·0	Rucksack .	8 0
	Yoke ..	20·0	Apron ..	16 0	Rucksack ..	9·0	Yoke ..	3·0

In the columns of the above table there may be perceived a few cases of apparent reciprocity in the height of the values, pressure being relatively high when pulse is relatively low, and vice versa. Thus at 40 lb. the pails are at the foot of the list for pressure, at the head for pulse (see also apron 40 lb., pails 30 lb., apron 20 lb., pails 20 lb.). There is, however, no general tendency in the direction of such reciprocity. This was ascertained by working out the correlation of the pressure and pulse increments for all readings, again for the initial (highest) readings only, finally and conclusively for the readings taken after the identical work of unloaded walking (166 exps.) which cuts out all interfering factors, and should show up the underlying tendency if such exists In all three cases r is of absolutely negligible proportions.

From Table LXIV as a whole, one may say that there is a general correspondence between the findings of the metabolic measurements and these determinations of the circulatory reactions. The differences are due chiefly to the heavier incidence of local strain in continuous carrying, and to the relatively greater disability caused in platform-walking by some gait peculiarities. With the 50 lb. loads, the reaction of pressure for head and for shoulder, and of the pulse for shoulder, head and pails, must be regarded as excessive, and indicating highly inefficient methods of carrying for this load. It is most probable that these reactions would become less excessive with training, but as the same is likely to be true of all methods, this does not alter the conclusion that methods accompanied by considerable disturbance to gait, posture or thoracic freedom, or causing local pain, make a demand upon the resources of the organism greatly in excess of what is necessary, and, that if the load can be more " physiologically " disposed, a saving, amounting, in the extreme cases of the 50 lb. load in the above table, to about 170 per cent. in blood-pressure rise, and 200 per cent. in pulse rate, can be effected with the same performance of external work, and a far greater capacity for continued effort.

Influence of Gait and Dislocation of Centre of Gravity.

Since the usefulness of the observations described in the last section depends entirely on the supposition that the platform allows, on the whole, of quite normal walking, it may be well to add the following notes, comparing the metabolic costs of walking on platform and in corridor respectively. The subject requires some time to get accustomed to the movement of the machine, and a large number of practice walks were taken before any experiments were attempted Still, in the early part of the approximately 200 experiments on which this report is founded, the cost of walking on the machine was still slightly higher than that of ordinary walking; before the end it was slightly less, because of the very accurate co-ordination which is developed in response to the machine's rhythm. This change is reflected

in the higher standard deviation for platform-walking than for corridor-walking in the XLV Table. In addition to these, Subject B, after a good deal of practice, did a series of 10 comparative walks, on machine and corridor alternately; for these her average net oxygen costs are, for the corridor 555 cc. per minute, for the machine 581 cc. per minute.

TABLE LXV.—*Net cost of walking on platform and in corridor. Subject A.*

	CO_2 c.c p.min	O_2 c.c.p.min.	Cal. p min.	S D. of O_2 determination.
Machine (av of 37 exps) .	354	408	2·01	30·2
Corridor (p 9 of Report 29)	343	421	2·01	22·7

A small series of metabolic experiments were made upon the platform, a 20 lb. load being carried for 15 minutes continuously —a reasonably long duration of work being preferable for respiratory measurements, even though it necessitated the use of only a light load. Table LXVI gives in order of descending costs, the average results of three, or sometimes two, experiments on eight modes of carriage. It will be seen that there is good general agreement with the results of the more extensive series of experiments in the corridor. The base-line used is the cost of walking immediately before the load-carrying—the values are therefore relative to each other, not directly comparable with the costs given in Section 1 of Part II of this report or in Report No. 29.

TABLE LXVI.—*Average net oxygen per minute.* 15 *minutes continuous carrying of* 20 *lb. loads on platform. Subject A.—Base-line walking.*

Hip	201
Head	182
Shoulder	177
Pails in hands	157
Tray	137
Tray with strap	124
Rucksack	90
Yoke	78

Two subsidiary points of some interest in the question of how, and how far, alterations of gait affect metabolic costs, gave rise to two short series of experiments on the platform. The first of these was designed to show how far the costs were affected simply by shorter pacing, the speed of walking being the same. The revolutions of the belt were kept constant, and the subject had to time her pacing to a metronome set to 96, 108, 116 and 120 beats per minute. Her normal pacing was 108 per minute.

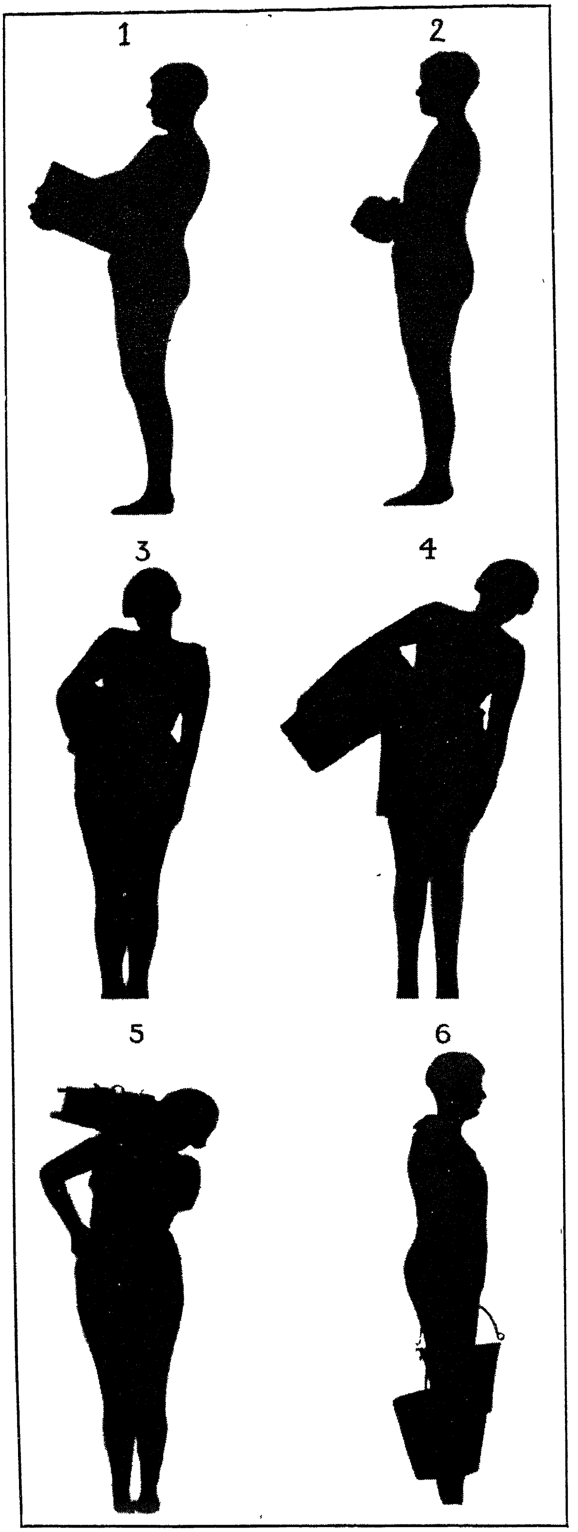

FIG XXXII. Various methods of carrying load, 1 and 2, in front, 3 and 4, on hip; 5, on shoulder, 6, pails supported by yoke on shoulders. The weight of the load is the same in all cases

This experiment was repeated eight times, the paces being taken in different orders. The average values are as follows :—

TABLE LXVII.—*Varying pace-length. Walking on the machine without load at constant rate.*

Paces per minute .	96	108	116	120
Net oxygen per min. c c	399	400	415	429

It appears that while the slower pacing makes little difference of cost (a *much* slower pace would almost certainly heighten cost, by making balance imperfect) a rise of about 7 per cent. in the number of paces per minute is associated with a rise of 3·75 per cent. in metabolic costs, and a rise of about 11 per cent. in pacing shows a rise of 7·25 per cent. in costs. It would seem then, that where the disposition of the load demands a shortening and quickening of the stride, an appreciable part of the rise of costs is due simply to the extra muscle work involved in making the extra leg movements.

The second point which was investigated was that of the additional metabolic cost involved in the assumption of an abnormal posture in walking, apart from the direct cost of the static and horizontal work of load-carrying. It is plain that there is a good deal of static muscular work in holding the body in a posture which throws the centre of gravity outside the base of support. Fig. XXXII gives some idea of the amount of displacement of the body which takes place as the result of carrying loads of various dimensions and in varying fashion. The weight of the load in all cases was the same. There must indeed be more muscular work in an active counteraction of false balance in the unloaded body than in the more passive counter-balancing, by the tilt of the body, of an external load added asymmetrically. The figures below (Table LXVIII), therefore, probably exaggerate the influence of posture on the cost of load-carrying, but show well how important in itself is the question of the displacement of the centre of gravity. Along with the abnormalities of posture, and hardly separable from them, are abnormalities of gait, due to the unequal incidence of the weight on the two feet, or to unfavourable angles for the working of the larger muscles of walking.

The degree of stoop or bend assumed was kept as nearly as possible at about that required by the carrying of a 40 lb. load in front, on the back and on the hip (middle width of tray) respectively For the " stiff leg " experiments, which were designed to elucidate the influence of this factor in the carrying of heavy loads on the hip, the upright posture was assumed as nearly as possible, and the knee-joint was splinted and firmly bandaged, a more complete immobilization of the joint than ever occurs actually in load-carrying. Each figure is the average of four experiments.

TABLE LXVIII.—*Costs of walking, without loads, in abnorma postures. Subject A.*

Posture.	Average net cost (c.c. O_2 per min)		
	Normal walking.	Abnormal posture.	Increase per cent.
Forward stoop ..	458	551	20·3
Backward stoop ..	466	592	27·0
Lateral stoop ..	435	580	33·3
Stiff leg	443	592	25·2

Summary.

1. The observations recorded in a previous Report (No. 29) are in all essentials confirmed.

2. The metabolic cost of carriage of loads would seem to depend, in large part, on the disposition of the load.

3. Any load which brings about any considerable departure from the erect posture, especially if this be associated with induced abnormality of gait, inevitably leads to a high physiological cost.

4 Methods of carriage which require much static effort are also costly.

5. Methods of carriage which bring about strain, especially on the smaller joints, although the load of itself need not overtax the individual, reduce the effective working capacity both by the local pain produced and from the efforts the worker makes by means of inco-ordinated muscular movements to gain relief.

6. The influence of varying load on the blood pressure and pulse rate was examined. The reaction of both blood pressure and pulse rate varied directly with the amount of external work done, but no exact proportional relation was found.

7. There was a general correspondence between the findings of the metabolic determinations and those of the circulatory reactions

8. The inference, so far as any can be drawn from the foregoing experiments, is that 50 lb. for "well disposed" loads and 40 lb. for "ill disposed" loads is about the maximum economic (physiological) load for women engaged in continuous work.

PART III.—LIFTING OF LOADS BY WOMEN AND YOUNG PERSONS.

By S. G. Overton, M.B., B.S., D P.H., H.M. Medical Inspector of Factories.

Introduction.

An inquiry was undertaken into the lifting of loads by women and young persons (aged 14–18 years), with two main objects; first, to obtain a fair indication of the loads actually carried by these protected persons in factories under normal conditions, and secondly, to supplement, for the industrial class, the anthropometric measurements described in Part I. It was decided to concentrate on industries that were known to be heavy, i.e., the manufacture of tin plates, pottery, sanitary pipes, aerated waters, bricks, paper, cotton, cutlery, woollens and worsteds, jams, sugar, confectionery, and engineering works.

The method followed was first to make, in each industry, a general survey of the work of the women and young persons and to discover on which processes weights had to be handled; and subsequently to weigh (without shoes), measure, and interrogate the worker, and to weigh the actual load which was being handled. A Jarasco weighing machine was utilised, and the information was entered on a special form. The Accident Reports were searched for reputed injury to these protected persons from weight lifting, and, wherever possible, the factory in question was visited.

In all, 512 cases of weight lifting were observed and recorded, and on these cases, with an additional 45 cases investigated by the Women Deputy Superintending Inspectors, are based the conclusions of this report. These numbers are all too small for important and possibly far reaching deductions On the other hand, although further data might alter the relative heaviness of some of the industries investigated, they would probably not materially alter the conclusions The aim throughout has been to obtain information and data relative to the *maximum* loads handled by women and young persons of average and less than average physique. Hence the averages calculated may be high for the industry as a whole.

Industries Investigated.

The full results of the inquiry are summarised in Tables LXIX to LXXIII (p. 127), according to whether they relate to young persons (aged 14—16) male and female, young persons (aged 16—18) male and female, and women. In the following section reference is made to the more important points emerging from the inquiry, as illustrated in Figs. A to F.

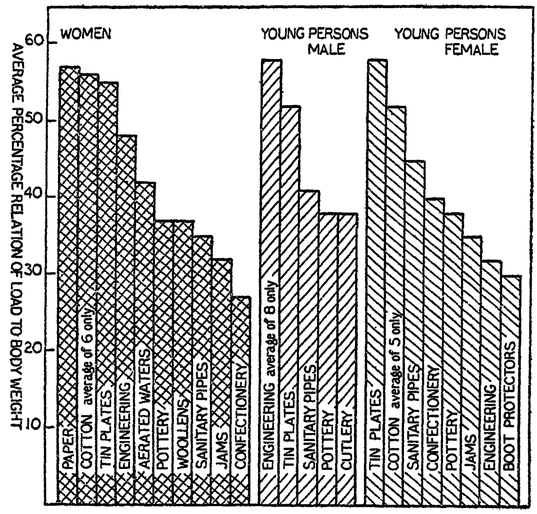

FIG. A. Average percentage relation of load to body weight in various trades.

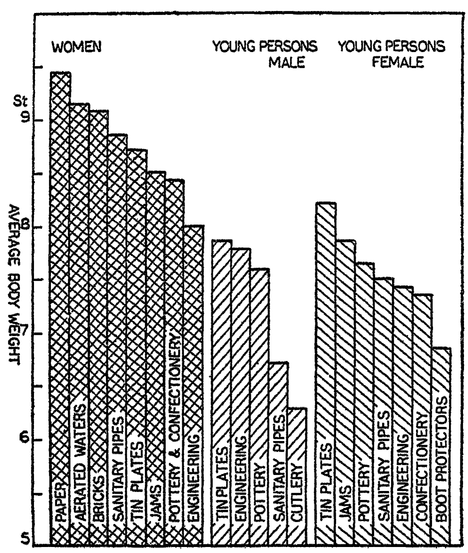

FIG. B. Average body weight of women and young persons, male and female, in various trades.

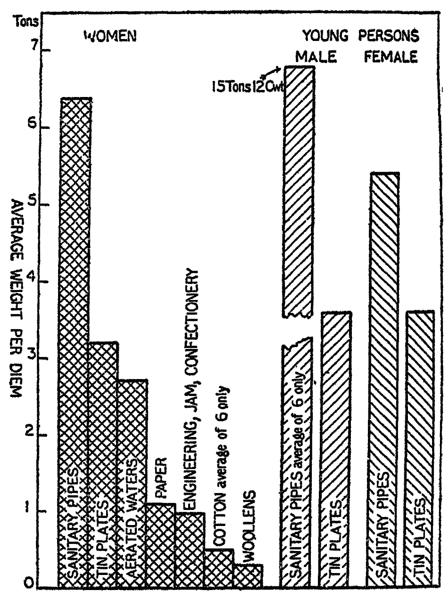

FIG. C. Average weight carried and/or lifted in various trades.

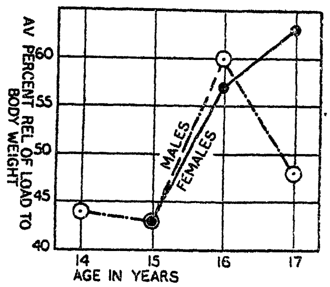

FIG. D Average percentage relation of selected load to body weight at various ages (young persons)

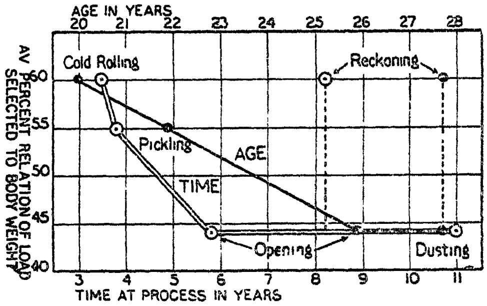

FIG E Relation between load selected and (*a*) average age (*b*) time at process, for various processes, by women workers in tin-plate trade

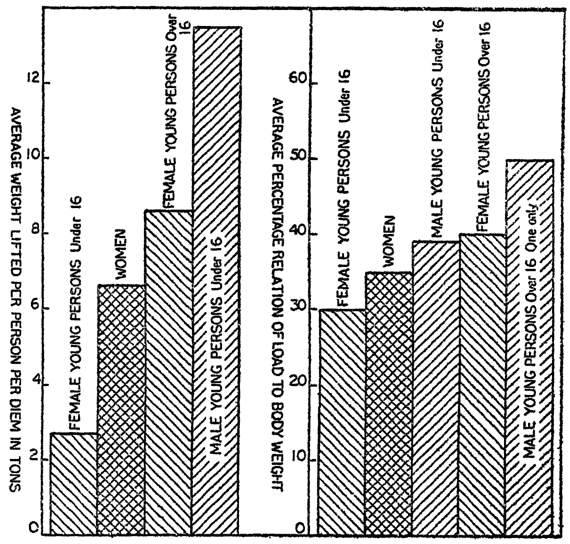

FIG. F. Comparison of (*a*) the average amounts lifted per person *per diem* and (*b*) the average percentage relation of load to body weight for the various groups examined in the sanitary pipe industry

Tin Plate.

A. Young Persons

From the point of view of weight lifting, the tin plate industry is one of the heaviest investigated. Lifting is an essential part of the several processes and although there is no work consisting of lifting alone, there is intermittent lifting and carrying throughout the shift, and as much as 7–10 tons are handled in one day by some of the young persons.

The average weight lifted *per diem* by male and female young persons is 3½ tons, and judged by this standard (total amount lifted and carried *per diem*) the tin plate industry ranks second among the heavy industries studied—sanitary pipes being first (Fig C). So far as the actual single load is considered, the average percentage relation of load to body weight in the tin plate industry is 58 per cent. for female young persons, and 52 per cent. for male young persons. Thus, so far as the inquiry goes, for individual loads the tin plate industry is second heaviest for male young persons and heaviest for female young persons (Fig. A). The worker (with the doubtful exception of the process of "reckoning," where young persons are rarely employed) can select the size of the load.

As regards the weight of the load selected by the young worker compared to his or her body weight, Fig. D shows that there is a steady rise in the weight of the load for female young persons from 15–17 years of age. A similar curve for male young persons (14–17 years) shows a steep rise between 15–16 years, followed by a drop between 16–17 years of age.

The female young person appears to be the steadier worker—practically it was found that the male young person often worked "in spasms." He would clear off a heavy load and then pause. The average percentage relation of load to body weight, including all processes, is higher for females than males in both groups, 14–16 and 16–18 years of age.

Mechanical means of lifting have been but little introduced into the tin plate industry One conveyor at the cold rolls was seen, but this only diminished the numbers of workers needed, and not the eventual amount of lifting and stacking to be done.

Physical condition of young persons as judged by casual survey.—Female young persons were of better physique and build than male young persons (Fig B). Round shoulders, hollow chests, were not recorded in any case of a female young person, but several times for male young persons Signs of distress—pallor, dilated pupils, sweating—were occasionally seen in male young persons, probably due to the spasmodic character of their work.

B. Women.

Women are chiefly employed in "opening," "cold rolling," "reckoning" and "pickling." In Fig. C for women, the tin plate industry is placed second for gross weight lifted *per diem*,

while it occupies the third position for the individual average load compared with the worker's body weight (Fig. A).

It is in the processes of cold rolling and reckoning that the highest percentage relation of load to body weight is recorded, and moreover the workers in cold rolling are younger than those in the reckoning and pickling processes (Fig. E). With the exception of reckoning—where the selective will of the worker as regards the weight of the load is partially ruled out —it seems that the younger the worker, the larger the load compared to her weight that she selects. Again, with the exception of reckoning, the shorter the time at work, the larger is the percentage relation between the selected load and the body weight (Fig. E).

Physical condition of women as judged by casual survey.—I was impressed by the health and vigour of the women. The conditions of work were particularly trying at the time of my visits and only three of 86 women appeared to be below par. None complained.

Conclusions.

Although a heavy trade, the workers in question—with the exception of male young persons—do not appear to suffer in consequence of the nature of the work. Inquiry into the heavy work of this industry seems to indicate that little or no harm is evident when such work is accomplished rhythmically and steadily—witness the record of the women and female young persons—whilst an effort, spasmodic in quality and quantity, may be followed by such signs of distress as were apparent even to casual survey among male young persons. It is evident, then, that young persons in general, boys in particular, need more supervision and warning against lifting a larger number of plates than is necessary. It is to be noted throughout that the physique of male young persons is inferior to that of female young persons among those examined in South Wales (Fig. B.).

2. Sanitary Pipes

The importance to this inquiry of the sanitary pipe industry is not so much the size and weight of the individual load, as the large amount of material lifted and carried during the day. For women, this industry heads the list for weight lifted *per diem*, with an average of 6·6 tons (excluding lifting, etc., with carriages), while for young persons, the amount lifted daily exceeds that in the tin plate industry, averaging 15½ tons (average of 6 only) for male young persons, and 5·4 tons for female young persons (Figs. C and F).

Among the heavy industries studied for the individual load in relation to body weight, sanitary pipes is placed eighth out of ten for women, third out of five for male young persons, third out of eight for female young persons (Fig. A).

In this industry, moreover, the size of the load cannot be varied according to the wish and strength of the worker, and the load is often carried some distance. Pipes in the green weighing 24–50 lb. are carried about 40 yards on the shoulder to be dried, and this work is practically continuous.

Another arduous and continuous process is the feeding of pipe making machines with wedges of clay. The daily output of each machine, if working continuously, may be as much as 20 tons. Much might be done for economy of labour, and consequent saving in output of energy, by altering the position of the feed of the machine with relation to the level of the slabs of clay with which the machine is supplied, so as to reduce to a minimum the lifting of wedges of clay from the floor to the feed (a distance of 1–2 feet), which at present materially increases the work.

The physique of the young person, and especially that of the female young person, in this industry was found to be poor, there were a few, however, whose movements when carrying pipes in the green were a joy to watch The women, who work at pipe making machines and with "dandy" carriages for the biggest pipes, are of average physique, but do not have such arduous work as some of the young persons (Fig. F) The average percentage relation of the woman's load to body weight is 35 per cent., and the daily weight lifted averages 6·6 tons, excluding those working with some mechanical contrivance such as a "dandy" carriage, which materially diminishes the strain of heavy loads (Fig. F).

A limiting weight for loads in this industry would need to be considered together with the daily total of material to be lifted.

3 Engineering

For male young persons this industry is the heaviest, in so far as the actual load compared with body weight is considered Engineering, for the woman and female young person, is less arduous (Fig. A).

A. Women.

But for the inclusion of the nut and bolt industry, the engineering industry would have occupied a relatively lower position among arduous occupations, for, except in this branch of the trade, women were not found to be lifting any weight of consequence, and the lifting was merely occasional and incidental to their work, i.e., moulding, press work, etc., nor were the loads carried any distance. In the nut and bolt industry, however, the loads consist of bolts in a pan, and these are collected by the worker and taken to her bench for press work. The size of the load is entirely left to the discretion of the worker, but influenced by the desire to minimise the number of journeys, she often selects excessive loads—in one case as much as 93 per cent. of her body weight.

The women in the nut and bolt industry have been "brought up" to the work and are of sturdy build—short, and rather thick set, a good combination for heavy work. In consequence, perhaps, no evidence of ill-health or accidents was obtained which could be attributed to the heavy loads they choose to carry.

B. Young Persons.

It is evident that the male young person often attempts to lift loads which are said to be outside his work, and which are certainly outside his capacity (Fig. A) The male young person is the one, among protected persons, who needs supervision in engineering. He is inexperienced, and does not know his own strength

Girls are on light jobs and do little weight lifting, except in the nut and bolt trade, where, however, the size of the load is left to their own discretion. This they seem to exercise very wisely in the direction of small loads

4. POTTERY

As will be seen from Fig A, the individual load in relation to the worker's body weight for this industry is placed sixth out of ten industries for women ; fourth, bracketted with the cutlery industry, for male young persons ; fifth out of eight industries, for female young persons. Except in a few cases, it was found impracticable to assess the total amount lifted *per diem*, as the amount varied widely from day to day.

A. Young Persons.

For young persons there is lifting incidental to work as a moulder's assistant, e.g., carrying of scrap clay, boards of unfired ware, and baskets and bungs of biscuit ware A few male young persons carry clay. The amount carried *per diem* varies from 400 lb. to 1 ton Among 30 young persons examined specially, four—three girls and one boy—showed signs of physical unfitness for the allotted work. In this industry, in contrast to the tin plate industry, the physique of the male young person is superior to that of the female young person, and this is specially noticeable in the 14–16 years old group, where there is a difference of 5 lb. in the average body weight to the advantage of the male young person (14–16), at an age when normally the girl is 4–5 lb. heavier than the boy.

In some of the potteries visited the regulations regarding weight lifting, clay carrying, and "permission to work" were widely posted, and in some cases their observance was enforced. In most cases, however, the young person is his or her own judge of the weight prescribed. More supervision and testing of loads is desirable if the weight limit of 30 lb. is to be of practical use. Several cases were detected where the young person was being overloaded by the senior for whom he or she worked.

B. Women.

Two women were observed to be moving tiles, aggregating 10 tons *per diem*. As a rule, however, the amount moved is considerably less. Women were usually able to share their load with another as the weight increased; baskets of ware for instance, were carried by two women. It was found that accidents attributed to weight lifting usually had some other highly important contributory factor—an unexpected obstacle in the way, a step backwards, etc. A few women were seen carrying clay, but for their own use as " makers."

So far as weight lifting is concerned, the women are wisely self-protective, and do not attempt more than they can manage. The average time at work ($6\frac{1}{2}$ years) is fairly high, and perhaps accounts for the moderate (37 per cent.) relation of load to body weight. Experience has no doubt been bought and is certainly a safeguard.

5. Paper.

This industry heads the list for the individual load for women, giving an average relation of load to body weight of 57 per cent. (Fig. A); while, from the point of view of the daily amount ($1\frac{1}{8}$ tons) lifted, the paper industry is placed fourth (Fig. C).

The workers are on piece rates and select their own bundles of paper for sorting. The woman who had been longest at the work—35 years—selected a load only 49 per cent. of her body weight, while a girl, aged 17, who had only been on the work 6 months, had a corresponding percentage of 70. Bundles of papers are carried in both arms, pressed against the body, and a distance of about 20 yards, or less, is traversed to the worker's bench. The women did not seem to be over exerting themselves and were of good average physique (Fig. B).

6. Aerated Waters and Beer Bottling

Aerated waters, with an average percentage relation of load to body weight of 42, comes fifth out of ten in the list of heavy industries for women (Fig. A), and third out of seven in the list of industries compared for the total amount lifted *per diem* per worker (Fig. C).

A study of the figures for this industry is of especial interest, however, as the worker cannot select the weight of the load. The latter can only be modified by obtaining help in the higher stacking of crates. The potential danger of lifting in this industry is the method of stacking the crates of bottles to a height, sometimes exceeding that of the worker. To attain this height, the crates are " jerked " up into position. There is thus a danger of sudden muscular strain to the abdomen and back. It is obviously very unsuitable work for pregnant women.

The work of two male young persons in a brewery was considered excessively heavy. The lifting was an essential part of the work, for crates of bottles, weighing $61\frac{1}{2}$ lb. were lifted down from a maximum height of 6 feet 4 inches to a washing machine, and this was done practically continuously for $8\frac{1}{2}$ hours.

It is suggested that in the aerated waters and beer bottling industries (1) crates of bottles should not be stacked to a height greater than 4 feet ; (2) young persons should not be called upon to lift crates unaided.

7. Jam Making

The loads of 53 workers (42 women and 11 female young persons) in the jam making industry were investigated. In comparison with the other industries, the individual load for this industry in relation to the worker's body weight (32 per cent.) is placed ninth out of ten industries for women, and sixth out of eight for female young persons (35 per cent.) (Fig. A).

The weights lifted in this industry were not considered excessive, except in a few individual cases where female young persons (14–16 years) not only had to carry a load but to raise it as well Lifting is generally only incidental to other work—labelling jam jars, filling, etc.—and most of the heavier work is transported on "bogey" carriages. More might be done, however, for economy of labour. There is an unnecessary amount of lifting up and down from benches where one move would be sufficient with some small adjustments. This can only be foreseen and provided by competent management. The need for such is great where unskilled young labour is employed.

8 Confectionery.

Thirty-seven cases of weight lifting in the confectionery industry were investigated, 29 among young persons and eight among women For female young persons the relation of the load to body weight averages 40 per cent , giving this industry fourth place out of eight in the list of heavy industries for female young persons (Fig. A) ; for women the corresponding average figure is 27 per cent., showing that for them this industry is the lightest for lifting and carrying among 10 heavy industries investigated

The average amount lifted *per diem* by female young persons is only 160 lbs , while for women the average amount is $\frac{7}{8}$ ton (1960 lb.) (Fig. C). Moreover, the loads are rarely carried far.

9 Cutlery

A large number of male young persons are employed in this industry, and in the Sheffield area the work of 18 was investigated (Fig. B).

The physique of these boys was poor on the whole, for the average body weight of 14 boys, under 16, was only 85 lb., or about 12 lb. less than normal

So far as the individual load in relation to body weight is concerned, the figure of 38 per cent. for this industry gives cutlery a share with the pottery industry of the fourth place in the list of heavy industries for male young persons (Fig. A). Two boys usually share a load, and where this is the case, the weights lifted do not appear to be excessive.

10. Miscellaneous Industries.

Boot Protectors.

A factory where iron boot protectors are made was specially visited as a large number of female young persons are employed. The weights lifted are not, in themselves, heavy, but the work involved much carrying up and down stairs of cardboard boxes containing boot protectors.

The physique of the female young person in this factory was of a very poor character (Fig B); the average body weight, 98 lb. for those of 14–16 years of age, and 89 lb. for those between 16–18 years of age, is very much below the normal The average of those under 16 was increased by the inclusion of an obese girl weighing 170 lbs, and a true picture of the physique of the remaining members of this group can perhaps be imagined. In addition, these young persons were found to be suffering, in a large proportion (47 per cent. in the younger group and 50 per cent. in those over 16 years of age), from some obvious physical disability.

The average percentage relation of the load to body weight for the female young person was 30, but the tiring character of the work, and the physical disabilities of many of the workers, must be considered with this apparently low figure.

Bricks.

I was favourably impressed with the physique and capacity of women engaged in brickfields. Most of the work consisted of wheeling bogies—often of single wheel type—loaded with bricks. These bogies are difficult to balance at first and cause some pain between the shoulder blades for a day or so on commencement of work. This is due to balancing of the load by movements of the shoulders. Most of the work is outdoors, and the conditions not only appeal to the woman of sturdy build but seem to improve the health and bearing of the workers (Fig. B).

Cotton.

In the weaving branch of this industry the loads consist of cast iron weights (50–100 lb.) suspended on the beam end. Four cases of weight lifting were investigated, and all complained of "strain" at some time. The average percentage relation of load to body weight was 42 per cent.

Baskets of bobbins, etc., are (1) lifted on to trolleys, and (2) dragged along ground by young persons giving an average percentage relation of load to body weight of 72·8. This work is seldom continued throughout the shift and the total weight moved is small. An attendant on scutchers, a female aged 52, moved daily about three tons of cotton lap, carrying 50 per cent. of her body weight at a time.

Woollen and Worsted Industry.

The maximum load encountered in this industry was a load of 180 to 190 lbs carried by two women. The weights in the woollen industry are heavier than in the worsted industry, and barrows are generally provided for moving the loads

Fish Curing.

Women roll barrels—two women to a 2 cwt barrel—but the barrels are pushed with a long spiked stick and are not heavy except on wet, heavy, or uneven ground

Conclusions.

Inquiry and search of records were made at two large provincial hospitals, tapping a wide industrial area.

One case of hydrocele in a boy of 16 in 1924 was alleged to have been caused by "strain at the works" (engineering). One woman, aged 22, doing heavy work in the war (1917) was said to have caused thereby a femoral hernia. Except for these two cases, no evidence of injury or illness attributable to heavy work for women and young persons was obtained.

Two surgeons—one at each hospital visited—gave as their opinion that, in their experience, so far as women and young persons were concerned, heavy work *alone* was not responsible for injury and that some contributory factor was always present. This opinion was largely borne out when accidents said to be caused by weight lifting were carefully investigated.

A comparison of percentage load is interesting between :—

Group (1) industries in which the worker *cannot* exercise his or her volition as to the weight to be lifted at a time, i e, aerated waters, sanitary pipes, pottery, cotton, woollens, confectionery,

Group (2) industries in which the worker *can select* the load to suit personal convenience, i.e, paper, tin plates (most processes), engineering

The industry with the highest percentage load for (*a*) women; (*b*) female young persons, and (*c*) male young persons, are all industries of group 2 Of group 1, where there is little or no selection of loads, sanitary pipes comes third among the industries studied for young persons (male and female), while aerated waters is placed fifth heaviest for women.

It seems from this comparison that (*a*) the work required of the woman and young person is, on the whole, well within their capacity, and (*b*) where selection of load is possible heavier weights are carried at work in which the load is made up of units of the standard size and weight demanded by the industry. Except on piece work where there is a premium on speed, women appear to be generally self-protective in their choice of the size of load, and know to a nicety their own capacity. On the other hand, young persons in general, and male young persons in particular do,

I consider, require more regulation and supervision in their work if they are to avoid overstrain in the physically exacting period of adolescence Of especial importance, where heavy work is continuous, is the maintenance of a steady rhythm well within the moderately extended capacity of the worker.

Under the heading of the various industries, a few suggestions have been made for the improvement of conditions for the protection of the worker, so far as loads and the adaption of the machine to the worker are concerned.

The industries that call for improvement on these grounds are those concerned with :—

1. Sanitary pipes.
2. Tin plates.
3. Aerated waters.
4. Engineering (especially in respect of male young persons).

In the opinion of the author, (1) 40 per cent. of the body weight for the individual load should not be exceeded for women and young persons, when the lifting and/or carrying is an essential part of the process, and is intermittent, if not continuous, throughout the shift , (2) 50 per cent. (somewhat less for young persons) of the body weight should not be exceeded for incidental and occasional loads.

In this inquiry into weight lifting, resultant definite injury to health has not been proved. Given a woman or young person of average nutrition, the work expected is almost always well within his or her physical capacity. It is here, as always, the sub-normal in physique and nutrition who presents the problem, and for whom, according to modern views and standpoints, protective laws are required. It seems, however—and this may lighten the practical difficulties—that the heaviest industries attract, or, perhaps more accurately, *retain* the strongest women ; the weaker gravitate through various trades and find their physical level. This is true for women, but much less so for young persons. Other factors in the choice of employment enter for this class of labour; for instance, proximity to the home would seem to be the first and sometimes the only consideration in the initial choice of an industry. No doubt the "below par" young persons filter through to a level of work which is within their capacity, but at what cost to the individual we can only guess. Certainly it is much greater than in the parallel case of the woman. For this reason, if for no other, the juvenile worker needs protection in the question of weight lifting.

Continued strain cannot but have a pernicious effect, which may only show itself indirectly in the multiple sequelæ of fatigue, increased incidence of accidents, lowered resistance to infection, increased suggestibility with its manifold and depreciating effects—to name but a few.

Finally, in the industries that have been investigated (with the exception of aerated waters, beer bottling, the process of "reckoning" in the tin plate industry, sanitary pipes, and occasionally pottery) it has not been *necessary* to the work to overstep the suggested limits of (1) 40 per cent. body weight for more or less continuous lifting and/or carrying, and (2) 50 per cent. of the body weight for occasional and incidental lifting and/or carrying.

Tables.

TABLE LXIX.—*Female Young Persons* (*14–16 years*).

Industry. (1)	No examined (2)	Average time of employment (years) (3)	Average body weight (lb) (4)	Average per cent. relation of load to body weight (5)	Average weight lifted per shift (tons). (6)
1 Tin Plate ..	4	8/12	109¼	44	3 5
2. Sanitary Pipes	6	10/12	100	30	2 7
3. Engineering ..	3	8/12	117	27	*
4 Pottery ..	8	2/12	101	29	*
5. Aerated Waters	1	4/12	113	46	1·6
6. Jam making ..	5	1·1/5	107	37	*
7. Confectionery ..	10	6/12	96½	43	07
8 Miscellaneous Trades .—					
(i) Boot Protectors	19	7/12	98	30	*
(ii) Potato Crisps	1	2/12	102	16	*

* Too variable to estimate.

TABLE LXX.—*Male Young Persons* (*14–16 years*).

Industry. (1)	No examined (2)	Average time of employment (years) (3)	Average body weight (lb) (4)	Average per cent relation of load to body weight. (5)	Average weight lifted per diem (tons). (6)
1. Tin Plate ..	10	8/12	104·6	43	3·5
2 Sanitary Pipes	5	1	89	39	13·5
3 Engineering .	1	3/52	94	77	*
4 Pottery .	5	6/12	106·6	33	*
5 Beer bottling .	2	9/12	115	54	2 6
6 Confectionery ..	1	2/12	84	24	2
7 Cutlery.. ..	14	6/12	85	38	*
8 Miscellaneous Trades .—					
(i) Boot Protectors	1	1	117	49	3
(ii) Crayons ..	2	2/12	119	33	—

* Too variable to estimate.

TABLE LXXI.—*Female Young Persons (16–18 years).*

Industry (1)	No examined (2)	Average time of employment (years) (3)	Average body weight (lbs) (4)	Average per cent relation of load to body weight. (5)	Average weight lifted per diem. (tons). (6)
1 Tin Plate ..	31	$1^{7}/_{12}$	116	60	$3^{1}/_{2}$
2. Sanitary Pipes	5	1	110	40	8 6
3 Engineering .	5	$1^{9}/_{12}$	96	36	*
4 Pottery ..	11	$^{8}/_{12}$	111½	44	*
5 Paper ..	2	$^{6}/_{12}$	124	58	$^{1}/_{2}$
6 Aerated Waters	3	$^{10}/_{12}$	127	43	3 1
7 Jam making .	6	$2^{3}/_{12}$	113	33	1
8 Confectionery ..	9	$1^{7}/_{12}$	115	35	07
9. Miscellaneous Trades —					
(i) Boot Protectors	6	$1^{4}/_{12}$	89	32	*
(ii) Brush makers	1	$1^{1}/_{2}$	132	28	*
(iii) Electrolysis of iron from pig iron .	2	$^{3}/_{12}$	145	21	*
(iv) Potato Crisps	1	$1^{10}/_{12}$	104	49	*

* Too variable to estimate.

TABLE LXXII.—*Male Young Persons (16–18 years).*

Industry. (1)	No. examined. (2)	Average time of employment (years) (3)	Average body weight (lb) (4)	Average per cent relation of load to body weight. (5)	Average weight lifted per diem (tons). (6)
1. Tin Plate ..	18	$1^{10}/_{12}$	$112^{1}/_{2}$	52	$3^{1}/_{2}$
2. Sanitary Pipes	1	$1^{1}/_{2}$	126	50	26
3. Engineering ..	7	$1^{3}/_{7}$	111	54	1
4. Pottery ..	6	$1^{9}/_{12}$	106	43	*
5. Jam making ..	1	2	93	22	2
6. Cutlery.. ..	4	$2_{1}/_{4}$	98	37	*
7. Miscellaneous Trades —					
(i) Boot Protectors	1	2	103	54	*
(ii) Bricks ..	1	3	127	40	*

* Too variable to estimate.

TABLE LXXIII.—*Women.*

Industry. (1)	No examined (2)	Average age (3)	Average time of employment (years) (4)	Average body weight (lb) (5)	Average per cent relation of load to body weight (6)	Average weight lifted per diem (tons) (7)
1 Tin Plate	86	$24^1/_2$	$5^9/_{12}$	112	54	3 25
2 Sanitary Pipes	18	$21^2/_{12}$	$4^4/_{12}$	124	35	6 6
3 Engineering	24	23	$4^8/_{12}$	112	48	$^3/_4$–1
4 Pottery	38	$26^9/_{12}$	$6^1/_2$	118	37	*
5 Paper	18	28	$6^1/_3$	132	57	$1^1/_2$
6 Aerated Water	16	$25^2/_{12}$	$3^7/_{12}$	128	42	2–7
7 Jam making	42	$24^1/_{12}$	$5^9/_{12}$	119	32	1
8 Confectionery	8	$21^1/_2$	$4^7/_{12}$	118	27	$^7/_8$
9 Cutlery	2	24	$7^1/_2$	117	70	*
10 Miscellaneous Trades —						
(i) Boot Protectors	1	18	—	92	31	*
(ii) Brush makers	15	$23^5/_{12}$	$2^7/_{12}$	122	28	*
(iii) Electrolysis of iron	5	$22^9/_{12}$	$^5/_{12}$	102	25	*
(iv) Crayons	6	22	$4^1/_2$	123	13	4
(v) Bricks	5	25	7	127	35	36 (max)
(vi) Potato Crisps	4	20	$2^1/_2$	125	25	*
(vii) Tobacco	3	22	4	123	20	$^6/_{10}$

* Too variable to estimate.

PART IV.—GENERAL CONCLUSIONS.

The answer to the question put can now be given with, we believe, a closer approximation to the truth than has hitherto been possible. As was pointed out in the first part of this report there were at least three lines of approach possible and all three have been followed.

In Part I we have given the results of out determination of a number of physical measurements in a fair sample of women engaged in industry. We admit, when the total number of women engaged in industry are considered, that our sample is but a limited one, which, moreover, does not embrace the total industrial area of Britain. Still the data, obtained as they were from a wide variety of places, probably do give, on the whole, a very fair representation of the type of women who are at present employed in industrial work. If this be granted then we may state that the average woman, who must be taken as our standard, weighs approximately 110 pounds, is 62 inches tall and has a pull of 183 pounds, a grip of 58 pounds and a crush of 50 pounds, or if we separate our industrial group into the official categories of (I) female young persons, 14 to 16 ; (II) female young persons, 16 to 18 ; and (III) women, the averages are in round figures as follows :—

	Weight pounds	*Height inches.*	*Pull pounds.*	*Grip pounds.*	*Crush pounds.*
I	99	61	165	53	44
II.	108	62	180	58	50
III	112	62	187	59	51

These figures, then, supply us with the basal data requisite for the determination of the average load to be carried if the physical characters of the bearers are to be taken as the basis of their fitness to carry.

An objection which might be raised is that body weight is a poor criterion of fitness to carry weight, that mere weight gives no direct indication of capacity, that some women may be heavy because they are muscular, others because they are big-boned and again in others the weight is mainly due to fat. Such an objection may be perfectly valid in individual instances, but our experience has shown that, viewing the women employed in industry as a whole, such an argument does not materially detract from the mode of assessment utilised by us.

When we turn to consider what is to be regarded as the *optimum* load stated as a percentage of the worker's body weight we find that the results obtained from the experimental work in the laboratory as given in Part II and those obtained from actual observations in factories as detailed in Part III are in fair agreement. The present series of laboratory experiments as well as those which were given earlier in Report No. 29 of the Industrial Fatigue Research Board seem to indicate that, with the refined technique employed, the optimum load for continuous carriage is one which is equal, on the average, to about 35 per

cent. of the body weight. The actual percentage depends to a considerable extent on the mode of carriage adopted by the bearer. It must of course be remembered that in these laboratory experiments both subjects employed were deliberately selected because they were inexperienced in the carriage of loads by any method. Although for the purposes of a comparative experiment where varying modes of carriage had to be investigated it was absolutely essential that the subject should be untrained in all modes, there is at the same time the loss of experience and training. If this be allowed for on the ground that in any one industry the female young persons will gradually be trained to the modes of carriage peculiar to their particular occupations, there is no difficulty in accepting the conservative values given by Dr. Overton as the results of her observations in actual factories. Dr. Overton comes to the conclusion that in the case of loads for continuous carriage they should not exceed a weight represented by 40 per cent. of the body weight and that for incidental or occasional lifts or carriage they should not exceed 50 per cent. of the body weight of the worker.

If these values be translated into terms of actual load based on the average body weight as determined in Part I they should be about 45 and 55 pounds respectively.

We hold that, although the method of assessing the weight to be carried on the body weight is valid for adults, in the case of female young persons, from a health and development point of view such a method should not be utilised, even although the child might be capable of handling the appropriate load.

Active growth and physical development is taking place between the ages of 14 and 16, the child's body is still in a very plastic condition, so that malformation and distortion of the skeletal frame work is readily produced. Constant carriage of loads, especially if the weight be excessive, tends to develop deformities, and this is emphasized if the mode of carriage is an unilateral one, necessarily interfering with the normal upright manner of walking. We are of opinion, therefore, that in the case of female young persons from 14 to 16 the load should not exceed 25 to 30 pounds, and in the case of the 16 to 18 group, (although our results show that growth has practically ceased by the age of 18, yet as the body between these years is still plastic, and should not accordingly be overstrained), a load of 40 pounds should not be exceeded. On the other hand for the average adult, although our data, translated into actual weight, indicate that a load of about 45 pounds would appear to be optimal for continuous carriage, we think that the body of the average healthy woman worker would not be in any way strained if the maximum load were placed at 50 pounds.

This load might be easily exceeded by as much as perhaps 20 per cent. in the healthy well-trained adult without throwing any undue strain on the organism when the load is a compact one and easily handled so that it does not interfere materially with the gait and balance of the bearer.

Our figure it must be noted refers strictly to the average woman in industry. There is at least one serious difficulty in fixing, if it were so desired, a definite weight as the limit of the amount to be carried, namely the fact that in industry the bigger and heavier women, i.e., those capable naturally of carrying the heavier loads, are either definitely recruited for or by a process of weeding out of the less fit are left in possession of, these occupations which demand the movement of considerable weights. Obviously if the weight were a fixed standard for all industries it might well happen that in some industries the workers would be unduly taxed whereas in others they would be working at less than their full capacity.

As a matter of fact, Dr. Overton's observations go to show that in many industries, in the case of adult women, at least, the load carried never approaches the 50 pounds figure, but on the other hand in other industries the load greatly exceeds this value. Our own limited experience has shown that, even in those cases where the worker is allowed to determine the amount of material to be carried in one journey, she very often selects, without any apparent injurious effects, a load much in excess of out optimal figure. The ill-effects of the carriage of loads in excess of what we believe to be the optimal may not be evident, indeed may be non-existent, if the woman be permitted to work at her own self-selected rate which would of course be commensurate with the load carried. If, however, the pace be forced and the worker harried, then just by so much as she is diverted from her own rate will the amount of physical exhaustion be increased.

In conclusion, we wish to thank those who have assisted us in carrying through the present investigation. In the first place we would thank the various owners, directors and managers who granted us access to the various factories and to, in particular, their welfare workers without whose aid the work would have been impossible. We wish to thank also the Ministry of Labour for allowing us to obtain data from the unemployed and to Miss Younger in particular for her personal assistance. Our thanks are due to Dr. Burnet, Director of the Glasgow Provincial Training College, for permitting us to use the women students of the College, and to Miss Milligan for her very great help and interest. We express our thanks to Mr. D. R. Wilson, Secretary of the Industrial Fatigue Research Board, for his patience, courtesy and ever-ready assistance in all our difficulties, to Dr. S. Dawson for his painstaking reading of the statistical treatment in Part I, to the various workers in the Institute of Physiology, Glasgow University, and in particular to Dr. Wishart, who assisted in carrying out the experimental work detailed in Part II, and above all to Dr. M. Greenwood to whom it is difficult to express the depth of our indebtedness in connection with the statistical treatment of the results, for without his skill, his criticism and his advice this phase of the investigation would have lost most of its value.

APPENDIX.

LEGISLATION IN REGARD TO THE MAXIMUM LOADS WHICH MAY BE CARRIED, DRAGGED, OR PUSHED BY CHILDREN, YOUNG PERSONS, WOMEN OR MEN

GREAT BRITAIN.

In Great Britain the Factory Acts at present in force make no reference to weight lifting or carrying, but the Factories No 2 Bill, 1926, Clause 47, contains provisions (*a*) forbidding the lifting or carrying by women or young persons of any load so heavy as to be likely to cause injury, and (*b*) empowering the Secretary of State to prescribe the maximum weight of the load to be lifted or carried by women or young persons, either generally or with reference to particular processes or classes of factories.

Requirements in general terms against the lifting or carrying of heavy loads occur in an Order of 1907 prescribing Special Conditions for Fruit Preserving (in respect of young persons) and in the Education Act, 1921, (in respect of children under 14), whilst the Regulations for the Manufacture and Decoration of Pottery (S R and O 1913, No. 2) prescribe a limit of 30 lb. to be carried by young persons under 16 and empower the certifying surgeon to require a lighter load at his discretion.

More recently, regulations specifying quantitatively the maximum loads for men, women and young persons in the Woollen and Worsted Industries have been made by Special Order (S R and O 1926, No 1463) These run as follows .—

1. No person employed shall by himself lift by hand any material, yarn, cloth, tool or appliance exceeding the maximum limits in weight set out in the Schedule to these Regulations

2. No person employed shall engage, in conjunction with others, in lifting by hand any material, yarn, cloth, tool or appliance, if the weight thereof exceeds the lowest weight fixed by the Schedule for any of the persons engaged multiplied by the number of the persons engaged

3. A piece of cloth in the long cuttle or a sheet of loose material shall not be deemed to be a reasonably compact or rigid body for the purpose of these Regulations.

Schedule

Person employed	Maximum weight where material, yarn, cloth, tool or appliance is a reasonably compact or rigid body.	Maximum weight where material, yarn, cloth, tool or appliance is not a reasonably compact or rigid body
	lbs.	lbs
(*a*) Man	150	120
(*b*) Woman of 18 years of age and over	65	50
(*c*) Male young person over 16 and under 18 years of age	65	50
(*d*) Female young person under 18 years of age	50	40
(*e*) Male young person under 16 years of age.	50	40

The following information relating to legislation in force in other countries is available through the courtesy of the International Labour Office.

Argentine

Order relating to the administration of the Act of 14th October, 1907, No. 5291, relating to the employment of women and children. Dated 15th October, 1913 (Annuaire de la législation du Travail, 1913, Bruxelles)

Article 49 lays down that the maximum weight which workers may carry both without and within the work rooms shall be —

10 kilogrammes for young persons of the male sex under 16 years of age; 5 kilogrammes for young persons of the female sex under 16 years of age; and 10 kilogrammes for women between the ages of 16 and 20 years.

Article 50 states that the maximum weight which may be drawn or pushed, including the weight of the vehicle, shall be as follows :—

Vehicles running on rails, 300 kilogrammes for young persons of the male sex under 16 years of age; 150 kilogrammes for young persons of the female sex under 16 years of age, 300 kilogrammes for women between the ages of 16 and 20 years.

Hand barrows, 40 kilogrammes for young persons of the male sex between 14 and 16 years of age

Three and four wheeled barrows, 35 kilogrammes for young persons of the male sex under 16 years of age, 35 kilogrammes for young persons of the female sex under 18 years of age, 50 kilogrammes for women between the ages of 18 and 20 years

Austria.

No special legislation except as regards workers in mining operations (order of the Minister of Agriculture, in agreement with the Minister of the Interior, dated June 8th, 1907, Article 2 of which stipulates that young persons—male persons aged from 14 to 16 years—shall only be employed in such mining operations as are suited to their powers and not detrimental to their physical development). (Bulletin of the I.L O, Basle, 1907, p.215.)

Bulgaria

Order relating to the enforcement of the Act regulating the organisation of handicrafts and corporations (July 23rd to August 5th, 1905).

Article 25 stipulates that no child under 14 shall be admitted to a trade unsuited to its physical strength

Trades are regarded as injurious if it is necessary for an apprentice to pass the whole day in a sitting or bending position, or to carry heavy objects exceeding his strength.

(Vide Bulletin of the I L.O, Basle, 1907, p 363.)

Chile.

Act No. 3915, fixing at 80 kilogrammes the maximum weight of sacks containing goods of any kind which are to be carried by man-power Dated 9th February, 1923. (Vide I L.O. Legislative Series, 1923, Chile 1.)

The weight of sacks containing goods of any kind which are to be carried by man-power shall not exceed 80 kilogrammes.

Regulations No. 2494, for the administration of Act No. 3915, dated 27th August, 1923.

1. A sack containing goods which is to be carried on the shoulder shall not weigh more than 80 kilogrammes.

2. Sacks not provided with handles (asas u orejas) may be dragged by iron hooks if they do not contain goods likely to be damaged in this way, provided than an agreement has been concluded to this effect between employers and workers

3 Sacks containing foreign goods which weigh more than the legal weight shall not be carried on the shoulder unless the weight is reduced to 80 kilogrammes

4. Sacks containing goods liable to increase in weight owing to damp or for other reasons, shall be deemed to comply with the Act even if they weigh more than 80 kilogrammes. For the purpose of calculating the tare the rules issued by the Department of Customs shall apply.

Finland.

Act: Commercial Assistants (October 24th, 1919) (Vide I.L O. Legislative Series, 1920, Fin 2)

Article 5 stipulates that a child or young person shall not be allowed to carry, lift, draw, or push heavy loads, nor to perform any other work which is liable to injure his health or hinder his physical development The Council of State is to issue special provisions respecting this

France

A decree dated 7th March, 1908, fixes limits as below for industrial employment whether in factories or workshops or elsewhere —

Sex.	*Age*	*Max Load (including vehicle). Kilos*
(*a*) Carrying weights.		
M	Under 14	10
	14–15	15
	16–18	20
F	Under 14	5
	14–15	8
	16–17	10
	18 and over	25
(*b*) Carriage in trolleys, on rails.		
M	Under 14	300
	14–18	500
F	Under 16	150
	16–17	300
	18 and over	600
(*c*) Carriage or barrows (*see* (*g*)).		
M	14–18	40
F	18 and over	40
(*d*) Carriage on 3 or 4-wheeled vehicles		
M	Under 14	35
	14–18	60
F	Under 16	35
	16 and over	60
(*e*) Carriage on 2-wheeled hand-barrows (*see* (*g*))		
M.	14–18	130
F	18 and over	130
(*f*) Carriage on tricycles and pedal machines (*see* (*h*)).		
M	14–15	50
	16–18	75

(*g*) Methods (*c*) and (*e*) are forbidden to males under 14 and to females under 18

(*h*) Carriage on hand-waggons (cabrouets) or pedal machines is forbidden to males under 18 and to females at any age

(*i*) Women within 3 weeks of confinement are not to be allowed to push or drag any weight, if the Manager has been informed of the date of the confinement.

Germany.

No special legislation In *Bavaria* the Police Regulations (November 21st, 1908) stipulate that no woman shall be employed in carrying loads in the building industry (Vide Bulletin of the I L.O , Basle, 1909, p 179)

Greece.

The Royal Decree of August 14–27th, 1913, lays down that children under 14 years of age) must not carry weights exceeding 5 kilogrammes, and young persons (under 18 years of Age) those exceeding 10 kilogrammes. Such persons are not to pull or push weights exceeding 300 kilogrammes on railway lines, or weights exceeding 50 kilogrammes on trucks or barrows. (Bulletin of the I.L.O., Basle, 1914, p. 223)

Hong Kong.

Ordinance : Employment of Children Dated September 29th, 1922. Date of coming into force, January 1st, 1923

Article 11 stipulates that no child shall be allowed to carry any weight which is unreasonably heavy, having regard to the child's age and physical development, and that no child whatever shall be allowed to carry any load exceeding 40 catties in weight (one catty—approx. : 600 grammes) (Vide I L O Legislative Series, 1922, H.K I)

Italy.

In 1911, at the request of the Ufficiale sanitario in Venice, the Ufficio del Lavoro expressed the view that no worker might be required to carry a weight equivalent to or exceeding half the weight of his own body Seeing that the weight of children between 12 and 18 years of age varies between 29·3 kilogrammes and 53·8 kilogrammes, the maximum load allowable for children might be assumed to be the following —

12 years	14·7 kilogrammes
13 ,,	16·5 ,,
14 ,,	18·3 ,,
15 ,,	20·9 ,,
16 ,,	23·6 ,,
17 ,,	26·3 ,,
18 ,,	26·9 ,,

Luxemburg.

The Act of August 23rd, 1877, deals with the matter in very general terms.

Netherlands

Decree issuing public administrative regulations under Section 10, subsection (1) of the Labour Act, 1919, Dated 10th August, 1920.

Article 1 stipulates that no young persons of either sex, or adult woman, shall be employed in any work involving lifting, pulling, pushing, carrying, or in any other way moving loads, if the said employment obviously, or, in the opinion of the chief of the district : (a) demands too great an exertion of his or her strength ; (b) is dangerous to his or her health for any other reason (Vide I.L.O. Legislative Series, 1920, Neth. 8.)

Portugal.

The Act of 1891 deals with the matter in general terms.

Russia.

Labour Code, 1922 edition (November 9th).

Article 129 provides that women and young persons under 18 years of age shall not be employed in particularly heavy and unhealthy work, or in work underground. A list of specially heavy and unhealthy occupations is to be issued by the P.L C., in agreement with the A.R.C.T.U., together with the provisions restricting the carrying of weights by women and young persons respectively. (See Legislative Series, I.L O., 1922, Russ. 1, p. 18).

Spain.

Royal Decree respecting classification of industries and occupations, in which the work of young persons under 16 years of age, and women under age, is prohibited or restricted (Dated 25th January, 1908.)

Section 8, on account of special conditions of work vide articles 4, 5 and 7.

Article 8 stipulates that no young person under 16 years of age shall carry burdens exceeding 10 kilogrammes in weight in factories, workshops, or other work places

Article 9 lays down that no young person under 16 years of age shall push or draw loads requiring a greater effort than is necessary to move the weights specified in the Article on level ground. (Bulletin of the I.L O , Basle, 1909, pp. 141 and 142).

Switzerland.

The Factory Act prohibiting the carrying of unduly heavy loads by pregnant women. Reference should further be made to the Administrative Order dated July 5th, 1923, relating to the employment of young persons in transport undertakings (Vide I L O Legislative Series, 1923, Switz. 1, p. 3.)

Victoria

The 1911 Labour Act prohibits the lifting and carrying of loads exceeding 13 kilogrammes by young persons under 18 years of age

Similar legislative provisions have been made in South Australia, but the I.L.O. is not in possession of the relative documents.

According to a report submitted by the Industrial Hygiene Department of the Australian Ministry of Health to the Industrial Hygiene Conference held in Melbourne in August, 1924, a scale of maximum weights is to be drawn up on the lines of the corresponding French regulations

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MEDICAL RESEARCH COUNCIL.

INDUSTRIAL
FATIGUE RESEARCH BOARD.

REPORT No. 45.

Two Contributions to the Experimental Study of the Menstrual Cycle.

I.—Its Influence on Mental and Muscular Efficiency.

By S. C. M. SOWTON and C. S. MYERS, M.D., F.R.S.

II.—Its Relation to General Functional Activity.

By E. M. BEDALE, M.A.

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PREFACE.

It has often been alleged in the past in regard to the industrial employment of woman that on account of the functional periodicity peculiar to her sex she must be unreliable as a " day in day out " worker; the fact that this periodicity is a normal physiological process is still sometimes overlooked.

For some years past, investigations have been in progress for the Industrial Fatigue Research Board in the expectation that in spite of the obvious difficulties to be met in research of this nature, some further light would be thrown on what was—and still is to some extent—a disputed question, namely the effect of the menstrual cycle on working capacity.

The following Report contains the results of two investigations conducted on different lines In the first of these, selected tests of mental and muscular efficiency were applied daily over periods ranging from six to nine months to thirteen University students and sixteen factory operatives, suitable precautions being taken to avoid any influence of suggestion by keeping the subjects in ignorance of the precise purpose of the tests. The data were then analysed and the performances about the time of menstruation compared with those during the inter-menstrual period.

The conclusions reached are (i) that the influence of normal menstruation is not greater than other influences of an accidental nature which may affect the performance of the tests at other times, and (ii) that the nature of that influence varies in different women and with their social status. Some show a worse, others a better performance of the tests during the menstrual period, while in others the menstrual period appears to have no influence. The fact that in some women the menstrual period may induce greater efficiency deserves attention, in view of the popular opinion to the contrary already mentioned

The second investigation deals with the more physiological effects of menstruation, systematic observations of basal metabolism, body temperature, and other physiological phenomena having been made over a period of three months. Whilst the results as a whole indicate a heightening of functional activity in the later inter-menstrual period and a fall at menstruation, this fall is no greater than others that frequently occur accidentally, and there is no evidence to suggest that a normal healthy woman is rendered physiologically ineffective during menstruation. Any conclusion to be derived from this investigation is limited by the fact that only a single subject was employed. As against this, however, the conditions were strictly controlled, so as to eliminate the influence of other variables, and in fact the rigidity of the conditions imposed over so long a period as three months made the use of other subjects impracticable. The Board, theretore,

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whilst recognising that owing to the narrow scope of the experiment the results cannot be regarded as generally applicable, have decided to include these in the present report, primarily as an illustration of the technique employed.

The combined results of the two investigations, whilst indicating the existence in some individuals of slight variations in efficiency and functional activity during the menstrual cycle, confirm the more recent work on the subject in indicating that this strictly physiological phenomenon has, as a rule, no noticeable effect on working capacity amongst normal healthy women.

Though definite data relating to actual industrial work are very difficult to secure, this view is strongly supported by inquiries made of different welfare workers in the course of another investigation into the physique of women as to the proportion of girls who suffered to such an extent as to interfere with their normal work. It appeared that very few of the women employed were so upset that they had to remain off work for even half a day, and that in the instances where menstrual trouble occurred at all (probably not amounting to 10 per cent of the women employed), this usually meant in practice that the woman merely had to lie down in the rest-room for about an hour and was then able to resume her work.

February, 1928.

I. THE INFLUENCE OF THE MENSTRUAL CYCLE ON MENTAL AND MUSCULAR EFFICIENCY.

By S. C. M. SOWTON and C. S. MYERS,[1] C.B.E., M.D., F.R.S.

CONTENTS

[1] The application of the tests and the preparation of their results were carried out by Miss Sowton, under the supervision of Dr Myers, who was also mainly responsible for the Report itself. His participation was made possible through a research grant given by the Laura Spelman Rockefeller Memorial to the National Institute of Industrial Psychology. Miss Sowton was an investigator to the Industrial Fatigue Research Board.

I.—THE PURPOSE OF THE INVESTIGATION.

It has been widely held[1] that the mental powers of women are weakened and that the co-ordination of their movements is impaired during the menstrual period; it has also been conjectured that they are influenced by the events of the entire monthly cycle. Such beliefs would *prima facie* seem to be capable of proof or disproof by the application of laboratory methods For the quantitative determination of the scope and accuracy of observation and attention, of the speed and precision of movement, etc , is (for other purposes) of common occurrence in the psychological laboratory; and the daily performance of tests that involve the exercise of such abilities would seem likely to demonstrate any changes in mental and motor efficiency associated with the occurrence of each menstrual period or with other phases of the menstrual cycle.

One such attempt has already been made in the United States, thirteen years ago, by Dr. Hollingworth[2]. Her general conclusion is that the menstrual cycle has no effect on the mental and muscular efficiency of normal women. But of the twenty-three subjects here submitted to experiment, only six were studied intensively. All these six were University graduates or teachers; and all but two of them (subjects F 1 and F 3) already knew the purpose of the experiment and were thus susceptible to the variable and obviously dangerous influence of such foreknowledge. Only the data of these six subjects were studied individually; and as in only two of these subjects could the experimental conditions be considered satisfactory, no adequate regard was payable to possible individual differences.

We have ourselves examined and drawn curves from Dr. Hollingworth's data, in the case of three tests given by her to the subjects F 1 and F 3 mentioned above. We find in these subjects no evidence of any menstrual influence on their performance of the test for speed in tapping. But in F 1 we find clear indications, at the menstrual period, of some *diminished* efficiency, in F 3, on the other hand, of *increased* efficiency at the test for steadiness of arm. (These opposite results will be found to correspond to our own.) In the test for fatigue of tapping—which was not given to F 1, F 3 shows unquestionably *diminished* efficiency at the menstrual period. Throughout her investigation, however, Mrs. Hollingworth was content to show that, when any lowering of performance occurred at the menstrual period, it was not greater than that which might occur at other times in the same subject. This demonstration—important as it

[1] Many striking examples of such published views are given by Mrs. Hollingworth in the book mentioned in the next footnote.

[2] Functional Periodicity—an experimental study of the mental and motor ability of women during menstruation. By Leta Stetter Hollingworth, Ph.D., New York City, Teachers' College, Columbia University, 1914.

is and, in general, confirmed as it is by our own research—cannot be held to prove that menstruation has *no* unfavourable effect on the performance of the tests. Our own investigations lead us to believe that it has an unfavourable effect in certain subjects and in the case of certain tests; whereas for other subjects and in the case of other tests the effect may be a favourable one or there may be no effect at all.

The social status of the remaining seventeen subjects, tested by Mrs. Hollingworth, was similar to that of these six persons; they were all University students. They were tested only every third day for only thirty days, at different hours of the day, and by different experimenters. Of these subjects we are told that "some" knew, "some" suspected, and "some" were ignorant of the purpose of the investigation. The data obtained from this group were necessarily treated as a whole, with the object of ascertaining whether the average performance of the *entire* group at the *one* menstrual period under examination differed from the average performance of that group on other days Valuable as was Dr. Hollingworth's work as a piece of pioneer research, it is clear that the whole problem demands re-investigation on a different scale, on subjects of different social status, from a different outlook and by different methods.

II.—THE TESTS CHOSEN.

The following tests, suitable for repetition day after day were employed in the present investigation:—

(1) The Number-checking Test (simple form).
(2) The Number-checking Test (modified form).
(3) The Spearing Test.
(4) The Dotting Test.

(1) The Number-checking Test (simple form).

The number-checking test (in its simple form) consisted of a sheet of figures containing the digits 0–9, which were arranged in irregular order (*see* Fig. 1) This sheet was laid before the subject who worked through each successive horizontal row of figures, marking three specified digits as directed.

The subject was instructed to draw a circle round every **5**, a cross (or oblique) stroke through every **6**, and a down (or vertical) stroke through every **3**, and to work as accurately and rapidly as possible without correcting mistakes. Each day's work at the test consisted in thus marking a single sheet. Three different sheets were used, which differed only in the arrangement of the digits. These three sheets were given in rotation on successive days. The scoring depended on the time taken, the best score being the shortest time in which the sheet was completed.[1]

[1] The sheets were examined for errors; but in these experiments, as in others with this test, it was found that the number of errors soon became negligible.

Put a CIRCLE round every 5, a CROSS STROKE through every 6, and a DOWN STROKE through every 3. Work as accurately and rapidly as you can. Don't correct mistakes.

4 3 2 4 7 3 9 5 8 6 5 4 0 8 7 6 3 2 1 7 9 5 7 6 4 3 2 0 2 9

5 0 0 6 8 4 0 1 3 2 7 0 3 5 6 7 9 1 5 8 4 6 7 0 3 1 5 8 7 1

7 6 8 1 3 8 9 0 5 7 6 5 7 2 4 3 6 3 8 4 2 1 5 9 0 7 1 6 8 4

6 2 1 9 7 0 3 4 2 5 1 3 1 0 9 6 8 5 1 6 7 5 0 8 2 4 6 3 2 1

9 0 5 8 3 2 5 3 4 6 7 9 1 9 5 2 4 6 7 2 3 9 6 0 1 5 8 2 9 0

8 3 2 7 9 6 0 6 8 2 6 1 0 5 9 2 5 4 2 5 8 1 3 7 3 9 3 0 4 1

4 5 7 9 3 6 2 5 0 5 1 7 3 4 2 7 3 9 8 5 6 4 7 2 9 1 8 6 1 0

3 2 0 6 9 7 3 1 5 3 6 0 2 4 9 7 5 8 6 8 8 7 9 5 0 3 1 9 2 2

5 1 8 7 6 1 5 5 0 9 8 6 3 0 0 6 9 8 1 2 4 3 0 3 7 8 9 5 4 7

0 2 3 7 5 0 9 2 3 8 6 0 1 2 5 4 6 7 9 3 8 6 4 3 1 9 5 8 7 2

7 5 2 2 1 3 0 5 7 3 3 9 1 0 6 8 5 7 4 2 6 0 1 6 9 5 4 2 7 7

3 4 7 7 4 6 3 0 5 9 1 3 8 4 2 6 8 5 7 1 9 6 4 2 8 5 9 3 4 0

5 8 9 2 6 4 3 9 8 3 7 4 2 6 9 5 8 0 5 9 0 5 8 6 4 3 2 1 0 0

4 2 6 9 3 0 1 6 5 7 8 2 4 3 0 9 6 8 9 1 6 0 8 3 8 5 5 9 2 8

0 3 0 5 9 0 3 8 7 3·1 4 3 2 0 6 9 1 6 9 7 6 2 5 4 2 8 5 8 0

4 8 6 9 3 7 1 6 2 6 4 0 4 5 2 0 7 3 9 5 8 0 6 5 9 8 3 1 7 1

5 2 7 3 4 6 2 0 9 1 3 8 7 6 4 1 3 9 5 8 1 6 9 7 2 5 4 5 1 4

3 0 9 6 9 8 7 6 1 5 0 4 2 1 6 9 8 5 3 5 7 2 0 3 0 1 3 2 4 2

2 2 5 7 5 1 0 4 5 7 9 3 8 2 5 0 4 3 0 6 4 1 3 2 9 6 8 6 2 4

1 6 1 5 4 6 6 3 9 7 1 0 8 6 4 1 3 2 4 9 7 0 8 5 3 4 5 2 9 7

3 2 2 4 3 2 6 0 3 6 5 5 7 1 9 3 8 5 2 4 6 0 9 1 4 7 8 2 1 0

8 5 0 6 7 1 5 6 9 0 8 2 4 5 9 0 3 8 2 3 4 9 7 1 3 5 8 6 1 9

3 0 1 9 8 3 1 3 0 1 6 5 2 4 0 5 1 6 9 8 7 3 1 6 2 5 4 0 7 2

4 6 2 7 3 2 6 4 3 9 8 1 5 0 3 9 7 6 5 2 5 4 6 0 8 7 2 4 0 1

1 0 5 5 7 3 1 6 0 8 6 2 3 4 0 5 9 2 5 7 1 3 8 2 4 1 6 0 0 8

FIG. 1

One reason for choosing this test was that it had already been employed in work on fatigue,[1] yielding results that suggested its sensitiveness to relatively slight variations in the condition of the subject. The test certainly demands a high degree of concentration of attention, and a good immediate memory. Speed of reaction is also of importance for its performance.

[1] Muscio, B, "Fluctuations in Mental Efficiency," *British Journal of Psychology*, Vol X, Part 4, p 344. This test is Muscio's "T.3."

(2) THE NUMBER-CHECKING TEST (modified form).

In the modified form of this test the digits of the same three sheets were divided on each sheet into two equal parts, (i) and (ii). Where this division occurred, fresh instructions for marking were introduced. There were thus six parts of sheets to each of which different instructions could be appended. The three digits to be checked and the three signs used in checking them remained the same as in the simple form of the test. The instructions now ran as follows:—

Sheet 1. (i) Put a circle round every 5, a cross-stroke through every 6, a down-stroke through every 3.

Sheet 1. (ii) Put a circle round every 3, a cross-stroke through every 6, a down-stroke through every 5.

Sheet 2. (i) Put a circle round every 6, a cross-stroke through every 5, a down-stroke through every 3.

Sheet 2. (ii) Put a circle round every 3, a cross-stroke through every 5, a down-stroke through every 6.

Sheet 3. (i) Put a circle round every 6, a cross-stroke through every 3, a down-stroke through every 5.

Sheet 3. (ii) Put a circle round every 5, a cross-stroke through every 3, a down-stroke through every 6.

It was expected that in its modified form this test would prove more difficult and would more clearly reveal any disability in the subject. But unexpected difficulties arose, which are described in the Appendix to this report, the method was therefore ultimately abandoned.

(3) THE SPEARING TEST.

The spearing test is an aiming test, previously employed by Muscio.[1] On a sheet of paper were printed ten small targets, each consisting of a bull's eye and of ten concentric rings 1 mm. apart (*see* Fig. 2, reduced in size). This paper was fixed to a board by drawing pins, and lay flat on the table in front of the subject who aimed at each target in succession by striking it with the "spear." The latter instrument was merely a needle fixed in a handle—an ordinary dissecting needle, in fact. At the start the subject rested the point of the "spear" on the front of the board and brought it back to that position each time after striking a target. The rhythm was given by a metronome, and the rate of target-striking adopted in the present experiments was 80 per minute. Three rounds of the same ten

[1] *Cf* *British Journal of Psychology*, 1922, Vol III, Part 2, p. 160. Here the test was scored, not by "points," but by "errors."

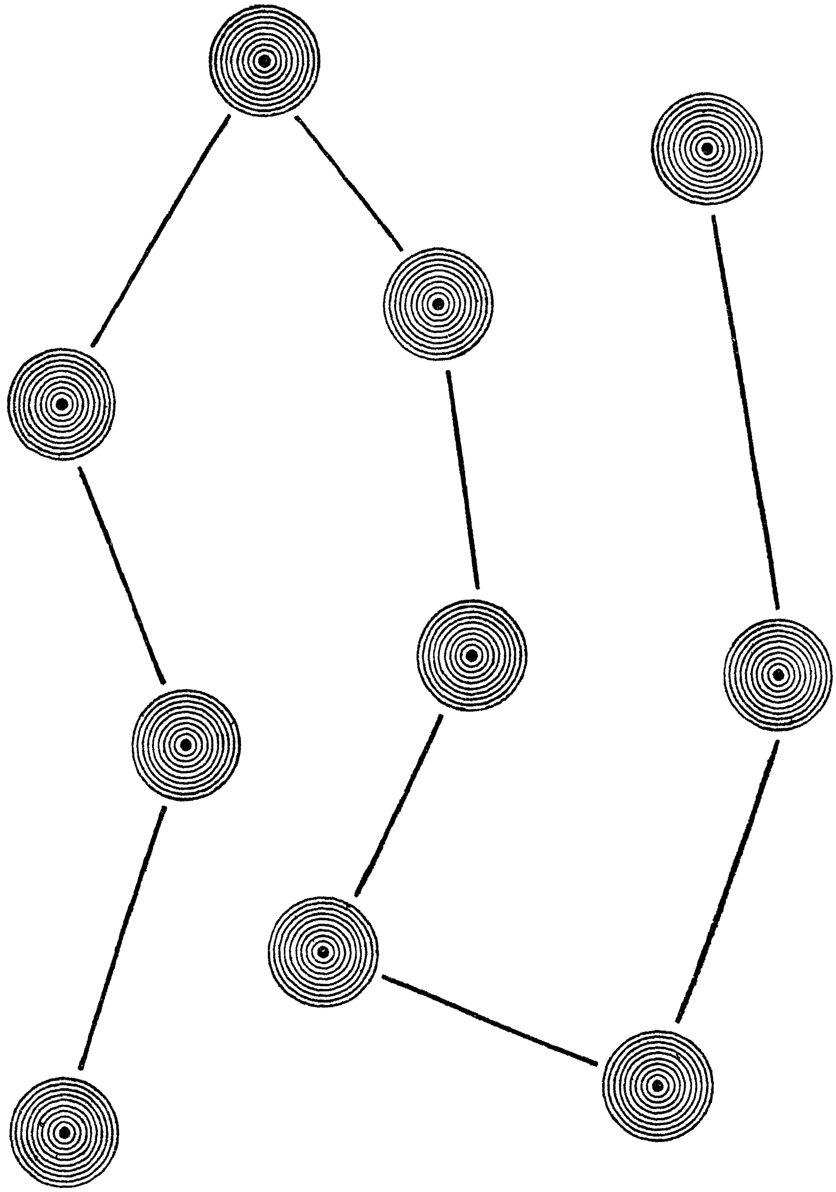

Fig. 2.

targets were made without pause at each sitting. The scoring was expressed in " points," a spear at the bull's eye counting 10, and one in any of the concentric circles counting 9, 8, 7, etc., according to its distance from the centre. Inasmuch as good co-ordination between eye and hand appeared to be important in this test, it was thought that if muscular movements suffered in precision during the menstrual cycle, this condition would be demonstrated by a diminution in the scores then obtained. The disadvantages of this test will appear later (p. 19).

(4) The Dotting Test.

McDougall's "dotting" test is so well known that it hardly needs description. The form of apparatus first used was found unsatisfactory, but a portable tape machine, which Dr. Edgar Schuster kindly constructed,[1] later fulfilled all requirements. The scoring depended on the number of errors, the best score being that with fewest errors. The reasons for adopting this test are explained in the Appendix to this Report (*see* page 42).

The effects of practice presented certain initial difficulties. But finally a fixed amount of daily work was determined which proved suitable to all the subjects. This consisted in the marking of 2½ metres of the paper tape (=500 dots) which passed the slit of the apparatus in 1 min. 59 secs

III.—THE VARYING DAILY CONDITION OF THE SUBJECTS.

A serious difficulty encountered at the outset of this investigation was that of obtaining precise information as to the onset and duration of each menstrual period It was essential that the subject should not be aware of the purpose of the tests, in order to avoid the unknowable and dangerous influence of suggestion. Consequently, no direct questions about menstruation could be asked of her. A simple procedure, however, served to provide the desired information, without—apparently—arousing in the mind of the subject any suspicion as to the real aim of the investigation. It also proved a source of valuable additional information.

In a previous use of the number-checking test for other purposes, Muscio[2] recorded at each test the subject's general condition. He asked her to indicate, by a mark, which of the four following terms best described her condition at the times of experiment. These terms were:—"fit," "fairly fit," "a little tired," "very tired."

In the present investigation this record was considerably expanded. Each of the subjects was daily given a bulletin which served to record her condition at the time, together with any changes of condition that might have occurred since the tests were last made. The subject ran her eye down the list, and filled in the appropriate letter or letters. For example, if she felt perfectly "fit," she put a capital "F" opposite that word; if she felt "a little tired," a small "t" recorded the fact; "headache" was indicated by a capital "H"; the menstrual

[1] We wish to express our thanks to Dr. Schuster for this and other help rendered in the course of our work.

[2] "Fluctuations in Mental Efficiency." *British Journal of Psychology,* Vol. X, Part 4, p. 330.

period by a capital "P," and so on. (See below for copy of the complete bulletin) "E+" might be used if the subject had been to the theatre or to a concert on the previous evening, or if she were anticipating some pleasure—a visit to friends, and so on; a difficult task in prospect might require "E—".

Each subject was told at the start—quite truthfully—that tests of her "fitness" were being carried out, and that the scheme required the careful recording of any mental or physical event that could possibly modify her condition in a favourable or an unfavourable direction. No surprise was expressed and no objection was offered to any inquiry made by means of the bulletin. "P" (the menstrual period) was only one among many items in the list; and this evidently appeared to the subject natural and reasonable.

DAILY BULLETIN

		Present Condition	*This Column was Filled in by the Subject*
One of these to be marked always	1.	Fit	F
	2.	Fairly fit	f
	3.	A little tired	t
	4.	Very tired	T
	5	Excitement, pleasant	E+
	6	,, unpleasant	E—
	7.	Headache	H
	8.	Other ache or pain	A
	9	Constipation	C
	10	Diarrhœa	D
	11.	Monthly Period	P
	12.	Worry	W
	13.	Sleeplessness	S
	14.	A cold	K
	15.	Medicine taken	M
For Subjects at the works.	16.	An accident	Q
	17	Heavy day (yesterday)	Z

IV.—THE SUBJECTS OF THE INVESTIGATION.[1]

1. Group A University Students.

The first group of subjects consisted of thirteen University students, who will be referred to as A1, A2, A3, etc. In response to an appeal at one of the Cambridge Colleges for women, thirteen members offered their assistance Their ages lay between 21 and 23 years, save in the case of subjects A6, A7, and A9 who were aged 29, 26, and 30 years respectively.

[1] We cannot sufficiently thank our subjects for the care and time they gave in carrying out the tests.

The testing was carried out on them daily (except on Sundays) during two successive terms. The work of the first term was from January 30th to March 31st, 1922; that of the second term from May 8th to July 1st, 1922. Two tests, the spearing and the number-checking (simple form) tests, were given every weekday at the same hour of the morning

2. Group B. Factory Workers.

Difficulty was experienced in interpreting the results obtained from the subjects of Group A, owing to the influence of practice. It was evidently desirable that the tests should be carried out for longer periods of time and in a less interrupted manner than was possible in the case of University students who were continuously available only during the eight weeks of term time. It was decided, therefore, to seek for subjects among industrial workers, whose holidays would be shorter. It appeared probable also that girls of a lower social status might be less practised in self-control, and that, in consequence, any variations in bodily or mental conditions due to menstruation would produce more obvious effects on performance tests.

Accordingly, Group B consisted of sixteen girls, all over 17 and below 29 years of age, who were employed by a firm engaged in the manufacture of scientific apparatus. They were a refined group of working girls; hence the contrast to the University subjects was not so great as was desired and needs remedying in some future investigation. Thanks are due to the Principal of this firm for making the experiments possible, his only stipulation being that the girls should be left absolutely free to take the tests or not, as they pleased. The first appeal to a number of girls produced eleven volunteers. These will be designated B1, B2, etc.

In this second series of experiments the following changes were made in the tests used. The "spearing" test was omitted; the "modified" form of the number-checking test was employed instead of the simple form; and later the dotting test was introduced in addition to or in place of the number-checking test.

The application of the number-checking test to the first eleven girls of this group began on October 2nd, 1922, and was continued until Easter 1923—that is to say, for six consecutive months. The test was given at the same hour every morning, and on every day except Sundays and Bank Holidays when the works were usually closed for several days. As before, care was taken to make no allusion to the menstrual period, unless the subject herself gave an opening by making some remark about it.

In this extended series of experiments with Group B, it was hoped that any practice effect in the number-checking test would have disappeared long before the six months were over; but this was not the case. There were many instances in which the "curve" continued to rise slightly each day even to the finish.

The dotting test, by means of the Schuster apparatus, was begun on November 20th, 1923, and continued until August 20th, 1924. It was applied to subjects B2, B3, B4, B5, B6, and B9. By November, however, various changes had taken place in the personnel at the works. Marriage or other causes had removed subjects B7, B8, B10, and shortly afterwards B11. B1 was not able to take the dotting test, as her eyes were weak and the strain of the test made them "water"; but she was quite willing to do something less trying. She was therefore given the simple (having already done the modified) form of the number-checking test. Five new subjects volunteered, thus bringing the remaining members of this group up to twelve. These five will be referred to as B12, B13, B14, B15 and B16; they performed only the dotting test.

V.—METHODS OF DEALING WITH THE RESULTS.

1. Simple and Compressed Curves.

In the earlier experiments the daily results of the tests were expressed graphically as "simple" curves. Two "simple" curves are reproduced as Figs. 3 and 4. But these proved difficult of interpretation in their original form Before their significance could be grasped, the long graphic records required "compression." Accordingly, the average of the scores for the days of any one "period" ("P") was taken as a unit, whether those days were few or many, and the average was termed the "P" unit. The preceding inter-menstrual days of the monthly cycle were then divided into units of the same number of days as composed the "P" unit, and the average value of each of these units was similarly determined. A graph of the thus "compressed" curve was then plotted.

This method has the advantage of showing the general trend of the curve, the general effect of practice, etc. Further, if the curve be fairly smooth, one is able to draw a line from one "P" point to the next and so on, and to consider this line in relation to the general curve. Should the "P" line thus drawn form a base to the general curve throughout the whole series of intervening units, this would indicate that the value of "P" was below that of the intervening units. The curve of B4 (Fig. 5) is an instance (the most striking example throughout the investigation) where the "P" line forms a base to the general curve. On the other hand, should the "P" line overtop the intervening units, this would mean that the "P" values were always above those of the intervening units. The value of any one "P" unit could also be judged according as neighbouring units were above or below the "P" line. This method proved useful, chiefly in relation to the number-checking records.

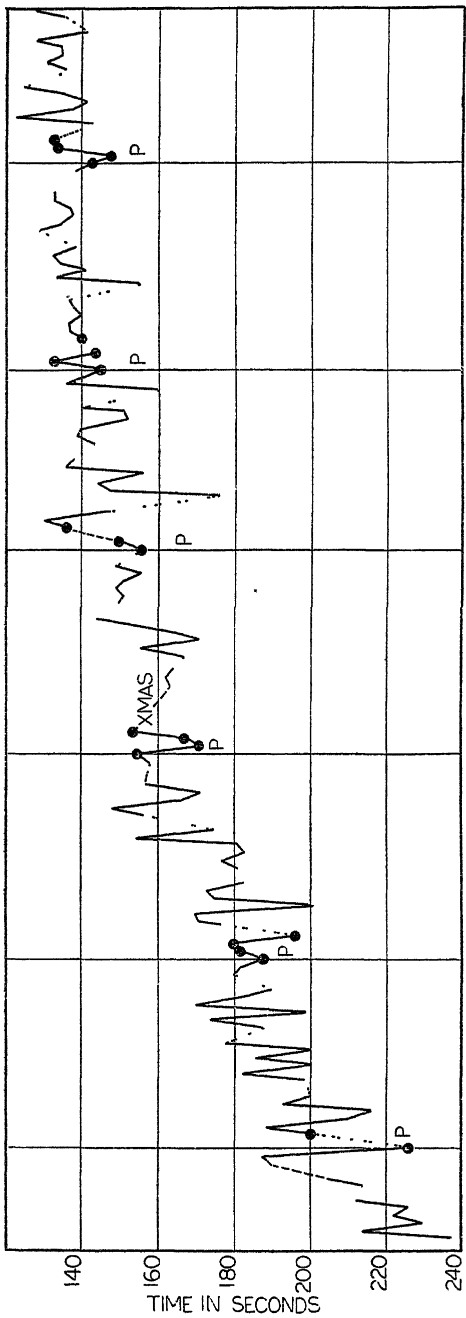

Fig. 3 Number-checking. Dotted lines indicate absence of subject on Sundays; broken lines absence on other days. The heavy dots indicate days of menstruation Subject B6.

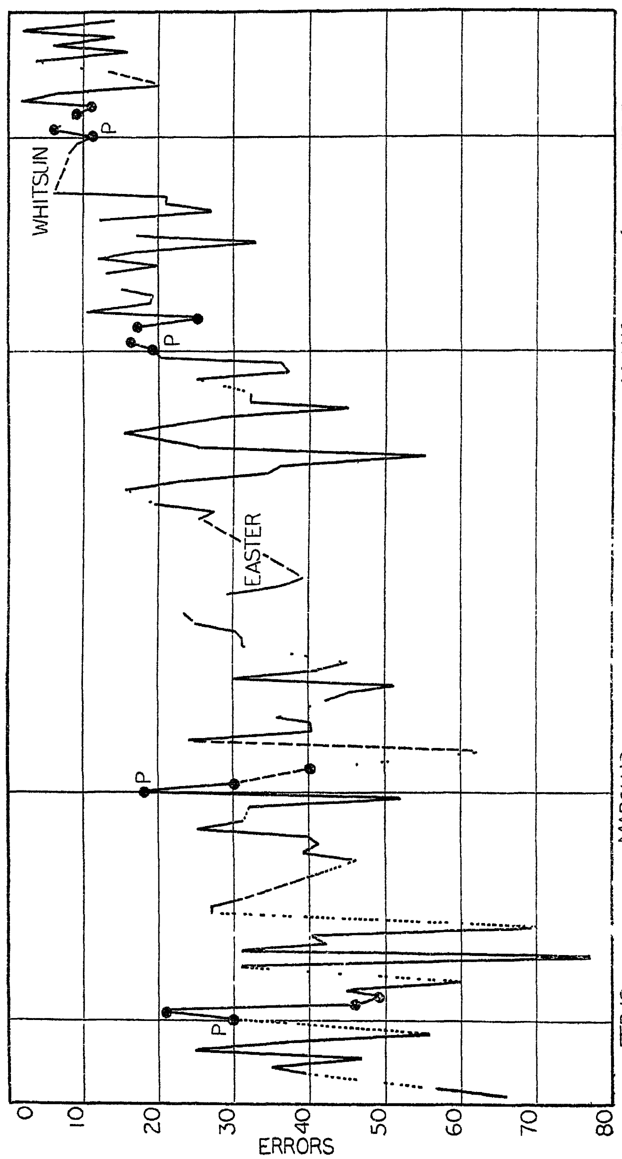

Fig. 4. Dotting. Subject B9 (*cf.* Fig. 3 for explanation).

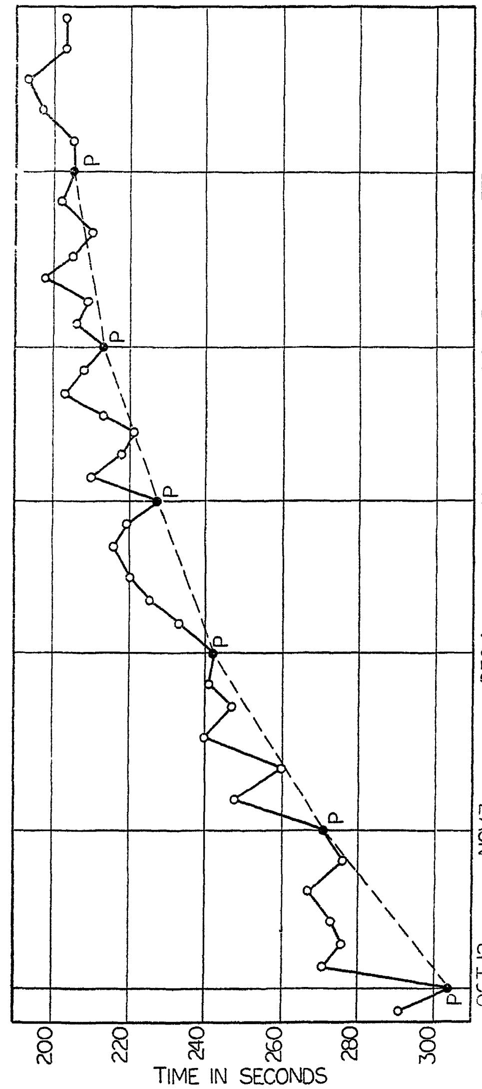

FIG. 5. Number-checking. Subject B4.

2. Composite Curves

Owing to the greater irregularity of the records in the dotting test (*cf.* Fig. 5), the " P " line seldom formed such a smooth curve. A further treatment of the records was therefore adopted. This second method was based on one previously used by Moore and Barker [1] and by Moore and Cooper [2] in their investigations of the same problem from the physiological side. These workers, finding that daily chance variations obscured periodically recurring changes, endeavoured to overcome the difficulty by " superimposing " the data for each monthly cycle, and by making a " composite " curve for each individual. This was done by arranging " the data of each cycle in successive rows, thus placing the data of corresponding days of the cycle in vertical columns. Thirty days was taken as the average length of the cycles, those which were more or less than thirty being arbitrarily shortened or lengthened in the inter-menstrual period so as to keep the days of the menstrual period in corresponding columns. An average was obtained for each day of the monthly cycle, and these averages were used to plot the composite curve "

" Composite curves plotted from the average values showed in practically every case periodically recurring variations. But the curves were still sufficiently irregular to warrant further smoothing. This was accomplished by a common statistical method; instead of using the averaged daily values, new values were obtained by averaging each with the values of the two adjacent days. This decreases extreme daily difference and brings out more clearly fundamental changes throughout the cycle."

This method has been used here (*cf.* B15, Fig. 6) with certain modifications. To prevent any misinterpretations arising from practice effects, the curve is arranged so as not to start with the " P " days; these are placed instead at some convenient distance within it. Further, no arbitrary length of cycle is here adopted, but the natural cycles of each subject are used; and where these vary in length in the same subject, days are sometimes omitted from the longer cycles if their retention would entail much

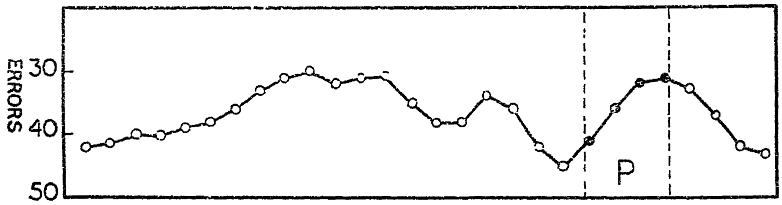

Fig 6. Dotting. Subject B15.

[1] " Monthly Variations in Muscular Efficiency in Women " By Lillian M. Moore and J. Lucile Barker. *American Journal of Physiology*, 1923, Vol 64, p. 405

[2] " Monthly Variations in Cardio-vascular Activities and in Respiratory Rate in Women." By L M Moore and C R Cooper. *Ibid.*, p 416

arbitrary filling-in. The important point is to keep the columns of days before and after the menstrual period in their right position with regard to that period, working backwards and forwards from the " P " days.

3. Statistical Examination.

Certain records selected from those which appeared the most promising for more thorough-going statistical examination, were submitted to the Statistical Committee of the Medical Research Council, and were subjected by Miss E. M Newbold to the following treatment :—In the number-checking test, each observation having been plotted as an ordinate against the calendar day of observation as an abscissa, a smooth curved line was drawn by eye through these points with the help of a spline. In the dotting test, where the practice effect seemed to be more uniform, the best straight line was fitted by the method of least squares This was taken in each test as the " practice line " of the individual. The deviation of each observation from this line was next measured, and (with its proper sign—the positive sign showing a worse, the negative a better performance than that given by the line) was assumed to be the measure of the performance of that day, freed from practice effect. The standard deviation of these deviations from the practice line was then found as a measure of the variability of all the observations ; the probable error was calculated ; and the results were treated as in the following instance, which relates to the number-checking test for subject B4 (cf. Fig. 5. p 13).

(*a*) Mean deviation from the practice line of 21 " P " days= $+ 7 \cdot 810 \pm 2 \cdot 079$.

(*b*) Mean deviation from the practice line of 111 non " P " days= $- 0 \cdot 712 \pm 0 \cdot 895$.

The difference between these two means, (a)–(b), $= + 8 \cdot 522 \pm 2 \cdot 26$. That is to say, the performance is significantly *worse* on the days of the menstrual period.

Again, in Subject B9, in the curve for the dotting test (cf. Fig. 4).

(*a*) Mean deviation from the practice line of 15 " P " days = $- 5 \cdot 686 \pm 1 \cdot 853$.

(*b*) Mean deviation from the practice line of 91 non " P " days = $+ 0 \cdot 825 \pm 0 \cdot 753$.

The difference between these two means, (a) –(b), $= - 6 \cdot 511 \pm 2 \cdot 00$. That is to say, the performance is significantly *better* on the days of the menstrual period.

These, however, are the only two cases of those submitted to such treatment, in which the difference between the two means, in relation to the probable error of that difference, proved to be statistically significant.

All, of course, that this indicates is that by the statistical procedure adopted, it is impossible to be fairly sure that the differences found in other cases are due to the menstrual period. They may

be so due, or they may be due to "chance" variations. But it does not mean that the other cases are to be discarded as worthless. Let us examine, for example, the simple number-checking curve of B6 (Fig. 3, p. 11). During the October, November, December and March periods, we can observe a distinct drop in efficiency, if we take into account the gradual rise of the whole curve due to practice. The February period is the only clear exception to the general rule. Further, in the simple curve for the dotting test applied to the same subject, three of the five monthly periods show distinct drops in efficiency, and in two of these and in the case of the three other periods there is a drop during the days immediately preceding the period.

But largely because fluctuations on the non "P" days are so wide (*cf.* p. 27 for the "Monday effects"), and because the results of non "P" days are treated as a whole and without reference to the proximity of some of these days to the "P" days, the above-described statistical treatment of the data for the number-checking test (those for the dotting test were not submitted to such treatment) yields the following result for this subject, B6:—

(*a*) Mean deviation from the practice line of 21 "P" days $= + 2 \cdot 048 \pm 1 \cdot 365$.

(*b*) Mean deviation of 111 non "P" days $= - 0 \cdot 505 \pm \cdot 582$

The difference between these two means, $(a) - (b), = + 2 \cdot 553 \pm 1 \cdot 48$. Hence, the worse performance on the days of the menstrual period appears statistically as non-significant.

Throughout the many records obtained in the course of this research, we have to recognise this important result, that the daily deviations from average efficiency occurring during the intervals between menstrual periods are generally not less than those occurring during the menstrual periods themselves. In other words, whatever effects menstruation may have on efficiency, they are usually not more harmful (and indeed, as we have just seen, may, sometimes at least, be more favourable) than other influences affecting performance at other times.[1]

4. The Influence of the Menstrual Cycle.

It must, however, not be forgotten that some of these other influences may be connected with the preparation for, or with the sequelæ of the menstrual period. For menstruation is now regarded by many biologists as being only an incidental, not as the essential, process of the whole monthly cycle. They look on it as a degenerative process of desquamation having for its object the removal of structural material which had been previously prepared against the possibility of pregnancy. Lasting usually for four days, it is followed by a five- or six-day "post-menstrual"

[1] For similar conclusions concerning variations in basal metabolism, *cf.* Glen Wakeham *Journal of Biological Chemistry*, Vol. XLVI, 1923, pp. 555–567.

period of regeneration of the uterine mucous membrane. Then ensues a nine- or ten-day " inter-menstrual " period of proliferation, dependent on the maturing ovarian follicle, at about the middle of which ovulation (*i.e.*, the escape of the ovum) occurs. Finally as, after ovulation, the corpus luteum ripens in place of the ovum within the ovary, comes the eight-day secretory or " pre-menstrual " phase, during which a deciduum-like bed is formed within the uterus to receive the ovum, if it be fertilised. Menstruation depends and follows immediately on the degeneration of the corpus luteum. It is thus not the climax of the monthly cycle, but rather the consequence of the climax of non-fertilisation of the ovum. The ovum is the ruling force of the cycle.[1]

We have therefore to be on the look-out, not only for the effects on efficiency exerted by the menstrual period, but also for those conceivably exerted by other processes (especially by those of internal secretons) occurring within other phases of the monthly cycle—notably those of the pre-menstrual and post-menstrual periods and those occurring at the mid-period of the cycle at or about the time of escape of the ovum from its follicle.[2] We cannot be content with contrasting (as in the above-mentioned statistical calculations) merely the " P " days with the non " P " days, although this is the readiest comparison and constitutes the main object of our present research. When, in addition, we consider that certain daily variations may be due to the encouraging or depressing influence of a previous day's performance of the tests employed,[3] we seem compelled to study separately and in detail the performances of each person tested, as they are revealed in the individual curves obtained.

VI.—THE EFFICACY OF THE TESTS.

Several objections may be brought against the validity of any conclusions drawn from this investigation.

It may be urged that the psychological effects of the menstrual period are more likely to become adequately manifest in affective changes—in emotional or temperamental changes—than in variations in performance of a daily test-task. This objection

[1] Cf. A. Seitz, "Der heutige Stand der Lehre der Menstruation," *Med Klin*, Vol. XVIII, pp. 1013–17, and W. Shaw, "Ovaries and Menstruation," *Journ. of Physiol.*, Vol. LX, pp. 193–207; for divergence from this view and for an attempted compromise between opposing standpoints, see F. H. Marshall, *Physiology of Reproduction*, 2nd Ed, p. 156 and *passim*.

[2] The effects of the pre- and post-menstrual periods are considered, to some extent, in this Report. In several subjects an attempt was made to trace any influence of other phases of the menstrual cycle, e.g., that of ovulation, to which the occasional phenomenon of inter-menstrual pain (*Mittelschmerz*) has been attributed. In most of the cases thus studied, there appeared indications of a fall of efficiency about this period, but the data do not warrant a definite statement on the matter

[3] The subjects were never informed whether their performances had been good or bad ; but there can be no doubt that they formed their own opinion, right or wrong, on this matter.

may be met by realising that such mental states as irritability, depression, excitement or discomfort cannot fail to influence the execution of any prescribed series of acts—whether, as in the various tests here employed, such acts depend for their success on voluntary control or on the unconscious co-ordination acquired by previous experience—provided that the methods of measurement are sufficiently sensitive to reveal such influences.

That the methods of testing employed in the investigation *are* sufficiently sensitive for such purposes is indicated by the large variations in performance, occuring on the non "P" days, which are associated with temporary bodily indisposition or mental stress. Of these we may quote several instances. In the case of A8, on the day on which she received the news of her appointment to a much coveted post, her score at the spearing test rose to 241 points from 190–223 points during the four previous days; and her performance at the number-checking test showed similar improvement. Again, B2 was subject to sudden brief, violent colds. For five days before one of such attacks, her time at the number-checking tests had varied between 190 and 200 seconds; on the day of the attack it rose (implying a worse performance) to 258 seconds—a figure never reached at any other time; two days later it fell to 189 seconds. During the summer term A6 was anxious about home affairs; she had come from the colonies and dreaded each mail day. The worst score she ever made at the tests occurred on a mail day. On two other occasions (*a*) when she felt "upset" and (*b*) when she was complaining of the summer heat, her score fell noticeably. She also showed a well-marked decrease in efficiency at the tests after an attack of influenza. B1 took a "tonic" prescribed by her doctor whom she had consulted for loss of weight and malaise; her score improved immediately. B5, when suffering from a cold, performed the test badly. B14 gave poor records when worried by troubles at home.

These illustrations will probably suffice to show the sensitivity of the tests. But a more important objection may be raised—namely, against the brevity of the tests employed. It may well be asked whether the performance of any test which lasted only a very few minutes can be considered as an index of the subject's efficiency throughout her daily work. This, of course, is a criticism which may be brought against any interpolated test of short duration. The subject leaves her work and approaches the test with interest, boredom, relief or dislike. She may bring to the test a degree of temporary excitement, or an ability to "spurt," which she would fail to bring to her ordinary work, or at all events to maintain, throughout the day. In this way the results may not reveal her true efficiency.

This criticism may be partly met by the consideration that it affects alike the performance of the tests when the menstrual period is present and when it is absent; and that consequently any differences in performance associated with menstruation may

reasonably be ascribed to its influence, even if—as perhaps in the cases of apparently increased efficiency during menstruation—they may not warrant any conclusion as to the ability to maintain such differences throughout the entire working day. Nevertheless, the criticism remains valid that longer test-periods might reveal differences which are hidden by the present methods of experiment.[1]

An attempt was made to correlate the results obtained from the tests with the output in industrial daily work of the persons tested in Group B. Early during the experiments upon this group, one of the managers of the Works was asked whether any data as to the output of individual workers would be available for comparison with the test results. But in his opinion no reliable data could be provided, owing to the unavoidably large variations occurring in the nature of the material handled by the girls.

Of the two tests employed in Group A, experience showed that the number-checking test was more likely than the spearing test to give useful results Efficiency at the latter test proved to be largely dependent on manual skill. The subjects who performed it easily and well were those who were good at games, and who had a lively " sense " of rhythm.

Several subjects observed that the spearing test was carried out automatically ; effort was of no use ; and to look intently at the target was a mistake. " You should just let yourself go," it was said ; and certainly the most successful subjects did their spearing with an easy rhythm that seemed free from conscious effort.

Number-checking, on the other hand, while calling for quickness of eye and hand, demanded such additional qualities as concentration of attention and memory. " Effort tells in that," as A11 said, and it seemed likely that more definite results would arise from testing qualities such as these rather than the more automatic reactions. Mainly for this reason, spearing was abandoned in group B

The experience of A5 illustrates the difference between the two tests. This subject found that on her " bad days " it was in number-checking that " want of condition " told. She noticed that after starting the test almost automatically, she became " shaky " about the middle of the page, and had to pull herself up. Spearing, on the other hand, gave her no trouble, for, as she said, it needed no concentration.

Further demonstration of the difference between the two tests is found in the records of A6. This subject was troubled with her eyes, and had them examined by an oculist. She came next day, saying that they had not recovered from the effects of the atropin which had been dropped into them, but that she would, nevertheless, like to see how she could carry out the tests.

[1] The validity of our experiments is confirmed by Kirihara's recent results (*see* page 24, first footnote).

There was, as might have been expected, a large decrease in her score in number-checking; but on spearing her impaired vision had no effect whatever.

The spearing test would therefore seem to depend for its successful performance chiefly on kinaesthetic rather than on visual experience. On the other hand, the same subject, who was much affected by the great heat on May 22nd, did the spearing test badly on that day; and on June 13th when she was much upset by home news and marked her bulletin "very tired" there was also a big fall in her efficiency at this test

Another example of this difference comes out in the records of A10. This subject broke her eye-glasses and on June 28th and 29th had to miss the number-checking test altogether; but she did the spearing test on these days without any marked falling off in scoring. She also remarked that "trying does not help you with spearing," whereas "number-checking is much more under control."

VII—RESULTS.

1. Adverse Effects of the Menstrual or Pre-Menstrual Period.

As we have already said on p. 15, an inspection of the curves of all the subjects tested shows only one case in which the menstrual period is, from the statistical standpoint there adopted, unequivocally associated with less efficient performance at the tests. This subject is B4. She carried out both the number-checking and the dotting tests, but the latter was interrupted by a two-months' absence, due to the illness and death of her father, which affected her deeply. Her "compressed" curve of number-checking has already been given (Fig. 5, p. 13). In it the "P" line forms a base to the rest of the curve, except at one point in the cycle of February, where a single unit of the non "P" days falls below the "P" line. Plotted as a "composite" curve, the results are equally definite. The "P" days and those immediately before and after them form a deep trough which occupies about one-quarter of the whole cycle.

In the dotting test, the data of the compressed curve for the same subject (*see* Tables), though far more irregular, leave no room for doubt as to the depressant effect of the menstrual period. The worst performances invariably occur on the "P" days.

Further evidence in support of these results is afforded by another test—the visual choice-reaction time. Here the speed of the subject's reaction to different colours was examined, she being instructed to respond by a different movement according to the colour which was presented to her. It will be observed (*see* Fig. 7) that again the worst performances are on the "P" days.

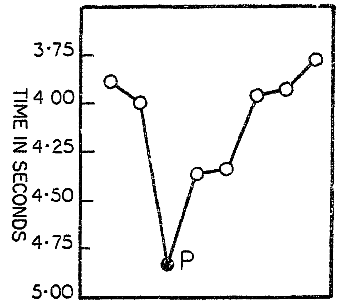

FIG. 7. Choice-reaction time. Subject B4.

This subject, B4, was of a reliable, friendly and communicative nature, and volunteered much valuable information. During her menstrual periods she often complained of fatigue and eyestrain. On several occasions, before starting the test, she stated that her head was not " clear," and added significantly, " there's a reason for it." This would often lead to conversation about her menstrual troubles, which were considerable. Sometimes she was obliged to go to the Matron's room and rest a little; severe bleeding at the nose was a feature of one such occasion The first day of her monthly periods was usually the worst. They lasted *always*, she said, from three to four days; but now and again, the bulletin gives only *two* days.

Although B4 is the only absolutely unequivocal case of invariably defective test-performance during each menstrual period, there are other subjects in which this feature occurs with fair regularity. The general depressing influence of the menstrual period is evident in the records of subjects B3, B6 and B7, of whom the last carried out only the number-checking test. The case of B6 (*cf.* Fig. 3, p. 11), a bright, capable girl, has been already dealt with, so far as number-checking is concerned. Her performance at the dotting-test reveals features of menstrual diminution in output, generally similar to those obtained from the number-checking test. In B15, who only did the dotting-test (Fig. 6, p. 14), a similar pre- (here followed by a post-) menstrual depression is also indicated; and it is noteworthy that this subject, a bright, artistic girl, aged 17, complained of often having " bad times " just before her periods. The menstrual flow apparently served as a relief to her, but at times she suffered towards the end of it. (In January and February, 1924, her period was delayed for one week, and in the following June an interval of seven weeks occurred without a period.)

The same effect is on several occasions revealed in the case of B3 (Fig. 8), the lowering effect being shown either at or immediately before the menstrual flow, or at both of these phases. This subject was a capable but delicate girl, who had at one time been under treatment for pulmonary tuberculosis. Her performance

of the dotting test was so irregular that no definite influence of the menstrual period is discernible.

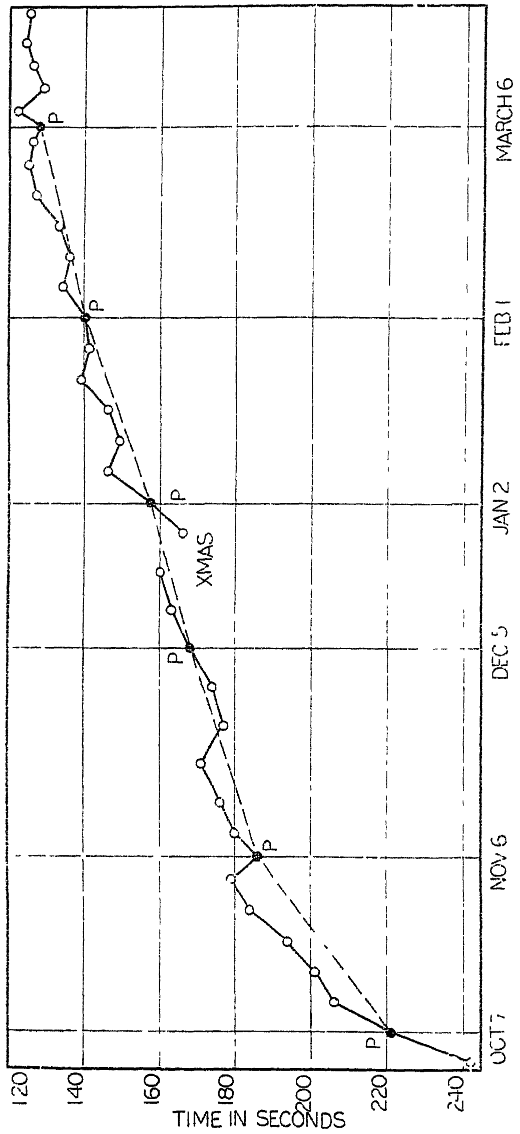

FIG. 8. Number-checking. Subject B3.

B7, who carried out only the number-checking test, was a delicate, excitable, impressionable girl. In the compressed curve drawn from the data afforded by this test (*see* Tables), an adverse tendency of the menstrual period is generally discernible. At one of her periods she complained of feeling "rather miserable."

In certain subjects, probably due to variations in their health the unfavourable effects of the pre-menstrual or menstrual period were sometimes fairly obvious, while at other times no effects could be traced. Of this, B16, who did only the dotting test, offers a good example (*see* Tables) ; she was a healthy-looking, but actually " nervy " girl, complaining of unaccountable fears when she rose in the morning.

Lastly, there are two subjects, A2 and B5, whose records, referred to later (p 29), suggest some lowering of performance associated with the menstrual period

2. Favourable Effects of Menstruation.

In striking contrast to these examples of adverse influences of the menstrual period, the records of B9 and B15 should now be considered. B9 was a shy but friendly girl of homely tastes, who preferred needlework to visiting the " pictures." She was apparently sensitive to a voracious appetite for food, excusing herself on the ground that " you cannot expect your body to work on nothing." The simple curve of her results for the dotting test has already been given (Fig. 4, p. 12; *cf.* also p. 15). In the compressed curve of her records at the number-checking test (Fig. 9), the " P " units stand for the most part high in relation to the non "P" units, especially to those of the pre- and post-menstrual periods. So, too, in the composite curve which summarises these effects (Fig. 10), the results on the " P " days present a peak of considerable height. In the composite curve

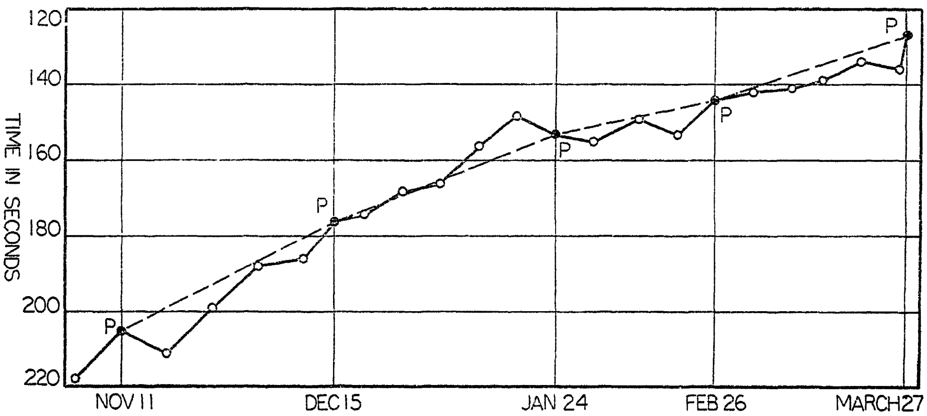

Fig. 9. Number-checking. Subject B9.

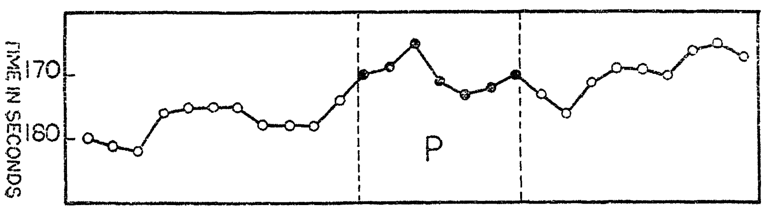

Fig. 10. Number-checking Subject B9.

of this subject for the dotting test (Fig. 11), the "stimulating" effect of the menstrual period is even better marked. The "P" days obtained for the four cycles February–June, combine to form a most definite peak. This subject complained of feeling depressed at certain monthly periods, but she said that she always tried to resist the feeling. Her good performance of the tests during menstruation may reflect such effort. But it is difficult to suppose that this is an adequate explanation of the greater efficiency so repeatedly revealed.[1] (*Cf.* also A10 below, who almost always felt "fit" during her menstrual periods, and our observations on p. 32 concerning the unusually high frequency of feelings of "fitness" among several subjects of this group.)

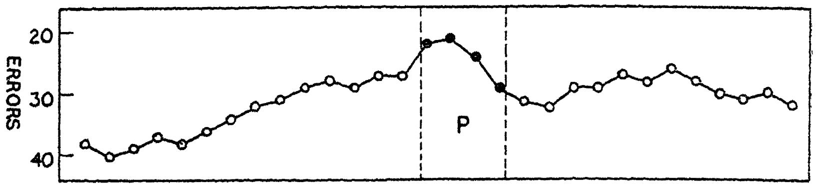

FIG. 11. Dotting. Subject B9.

The composite curve of B15 has been already given on p. 14 (Fig. 6), and her general character has been described on p. 21. Her improved efficiency during the menstrual period followed a pre-menstrual fall.

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[1] Reference may here be made to certain data obtained in the course of a recent inquiry, published in Japanese, by Dr. Houken Kirihara, to which our attention was directed by Mr. D. R Wilson, after the completion of this Report. These are to be found in a journal which bears the title in Esperanto, *La Studo por la Scienco de Laboro* (Vol. III, No. 2, August, 1926, pp. 265–328), published by the Institute of Industrial Science at Kurosiki. This paper deals with the output of 30 women workers engaged on day-shifts in reeling at a spinning mill and with their variations in output at different phases of the menstrual cycle Of these 30 women, 5 are classed as "uncertain" in their results, and 2 are omitted as suffering from amenorrhœa. Of the remaining 23, 7 show a fall in output during the pre-menstrual phase (Type A), 11 show a fall during the menstrual period (Type B), 3 *show a rise during the menstrual period* (Type C), and 2 show no influence of the menstrual cycle (Type D).

Our attention has also been drawn to a recent report entitled "The Effect of Functional Periodicity on the Motor Ability of Women in Sports," published at Ann Arbor, Michigan, U.S.A , by Professor Gertrude Bilhuber, in 1926. Her general conclusion is that the "menstrual periods do not appear as times of particular inefficiency" in carrying out the gymnastic and athletic performance tests which she applied to her fourteen women subjects. But it is of interest to find the following remarks "Indeed it appears that if conclusions may be drawn from the limited number of subjects studied, *menstruation may be a period of increased efficiency of movement*" (p. 45). A similar conclusion in regard to tests for steadiness and for adding has been even more recently reached by Helen E. Eagleson, *Comp. Psychol. Monogr*, 1927, Vol. IV , No. 20, pp. 39, 42, 62. *Cf.* also our footnote to p. 34.

A8 and A10 are two further instances where an improved performance of the tests at menstrual periods is probably indicated (*see* Tables). Subject A8 was a bright, friendly girl suffering at times from " rheumatism " and " neuritis," who was particularly keen on the performance of the tests. In the summer term she was incapacitated for several weeks owing to an injury to her foot, but she insisted on going on with the tests. Only two monthly periods are available for study, but they show the same favourable effects during menstruation, both in the number-checking and in the spearing tests. A10 was a bright, healthy, " original " girl. Improved efficiency is shown strikingly in one and less markedly in two others of the four periods recorded in the number-checking test; but no definite conclusion can be drawn from her performance at the spearing test. This was a subject who observed that trying was of no assistance in the spearing test, whereas the number-checking test was much more under control.

3. The Influence of Novelty and Practice.

In A1, B1, B8, and B11 (each of whom, with the exception of A1, carried out only the number-checking test), the monthly period seems at one stage to exercise a favourable, at another an unfavourable effect on the performance of the tests.

Of these A1 was a quiet, thorough, steady-going girl, aged 23, whose record contained no indications of ill-health or worry during the application of the tests. Her periods only lasted two days and recurred frequently, three being recorded in each term of eight weeks. B1 was a refined, quick, keen girl of nervous and delicate appearance. She often felt " out of sorts." On December 18th she consulted her doctor, because she had been losing weight. He gave her a tonic, following which a brief increase in efficiency at the test resulted (*cf.* p. 18). She complained of eye-strain when asked to carry out the dotting test; for this reason she was given, instead of it, the original form of the number-checking test, and showed similar tendencies. B11 was a sensitive, retiring, sad-looking girl, fairly healthy but often tired towards the end of the week. She did not perform the dotting test.

In the case of A1, B1, and B11 (*cf.* Fig. 12 and Tables), the output shown in the number-checking test is increased (or at all events not diminished) during the first few monthly periods recorded, whereas in the later monthly periods there is an undoubted diminution in output. (The same phenomenon is also indicated in the spearing record of A1, Fig. 13.)

This we are disposed to ascribe to the effects of excitement during the stage of novelty, although it is partly explicable, in the case of A1 and B11, by strain and worry felt towards the end of the test series. For it is conceivable that during menstruation such effects will be especially potent owing to diminished control (or inhibition) of reserve powers, and that they overcome any

intrinsic depressing effects, associated with menstruation, which would otherwise become manifest, and which actually do become manifest after the work has reached a less interesting, more "automatic" stage

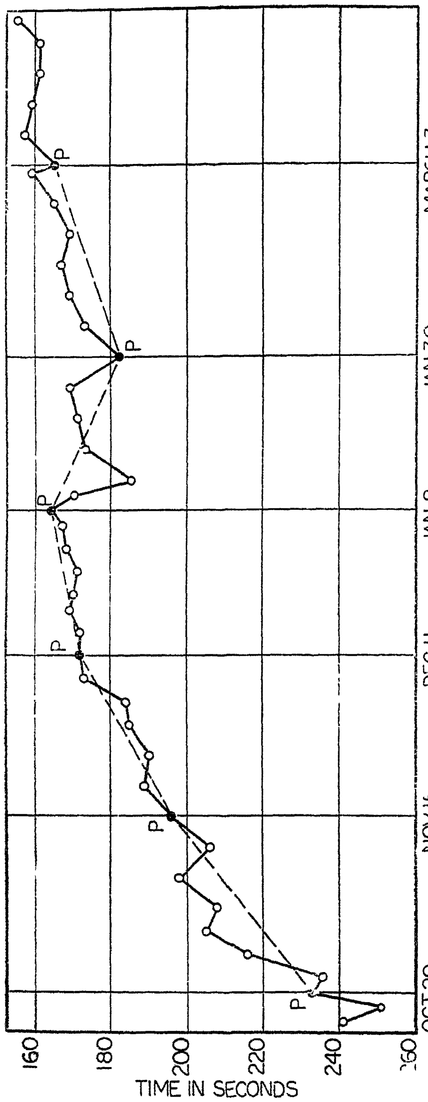

FIG. 12. Number-checking. Subject B11.

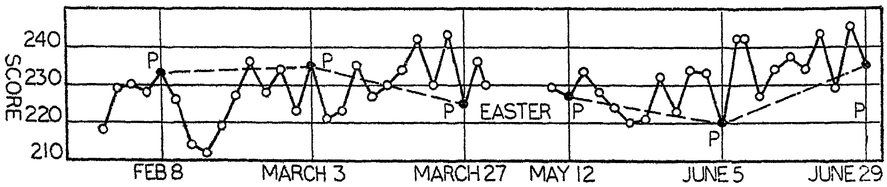

FIG. 13. Spearing. Subject A1.

Further confirmation of this explanation is obtained by an inspection of the " Monday effect " in the simple curve of the number-checking test previously given (*see* Fig. 3, p. 11) for B6. (The Monday performances are easily recognised on the graph, inasmuch as a dotted line indicates each Sunday absence). In the early stages of practice, when the test has the attraction of novelty, *improved* performance is the general rule on Monday mornings, as compared with the previous Saturdays ; whereas in the later stages, the more usual *adverse* effect of the week-end absence is—with one exception—invariably reflected on the subject's Monday performances of the test. As in our study of the effects of the menstrual period, it is noticeable, however, that some individuals (*cf.* the simple curve of B9 for the dotting test, Fig. 4, p. 12) generally do better after the week-end rest, and that others almost invariably do worse. For example, on twenty consecutive Mondays, B2's performance at the number-checking test is always higher than on the previous Saturday's; whereas at the same test on twenty-one consecutive Mondays, B4's performance is worse than the previous Saturday's in twenty cases. Returning now to the subjects A1, B1, and B11, they all show a tendency towards a favourable Monday-effect in the early stages of practice at the number-checking test and towards an unfavourable effect after the novelty has presumably disappeared. We appear justified, therefore, in attributing the contrary effects of the menstrual periods in these subjects at different times (partly, at least) to the influences of novelty and monotony.

On the other hand, in B8 (Fig. 14) it is in the early stages of the application of the test that the monthly period shows an adverse effect, while later it has perhaps a stimulating effect. Is it too fanciful here to suppose that during the early stages of practice, this subject may have suffered from anxiety which far outweighed the effects of greater excitability, normal to this subject, during the menstrual period, which effects later became free to manifest themselves in the form of higher output ?

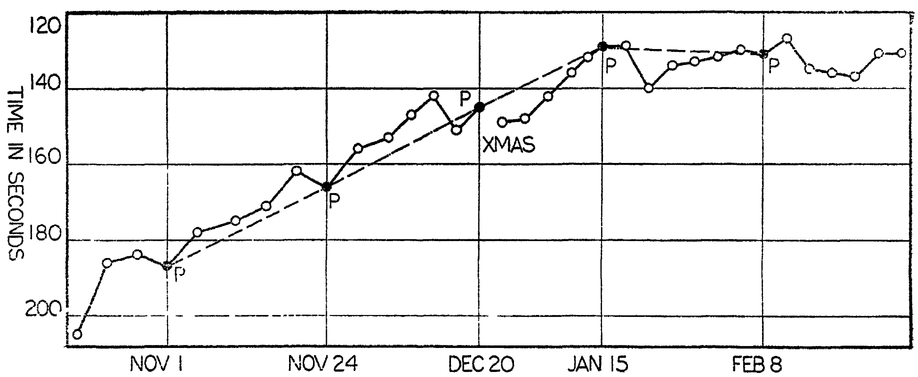

FIG. 14. Number-checking. Subject B8

This subject was an intelligent girl of apparently good physique, but much affected by changes in weather, suffering at time from "rheumatism" and "neuralgia," and apt to feel tired towards the end of the week. Like B11, she left the works before the dotting test could be carried out

4. No Effects of Menstruation.

In several subjects we have clear evidence that menstruation has no effect at all on the performance of the tests. For example, the compressed number-checking curve of A11 might pass for a typical practice curve, and that of A4 is almost as smooth (Fig. 15). Both these subjects were bright, cheerful, healthy girls, aged 22, and were very keen and energetic. They performed the tests excellently and were highly skilled in games. The spearing test came very easily to them. In the case of A4, however, there occurs a fall in the curve of the spearing test (*see* Tables) at her third monthly period. This is noteworthy, because the daily bulletins describe her as perfectly "fit" on each of the four days of this period, whereas in the other three periods recorded there were always some days on which the feeling of fitness was "below par," and nevertheless, there was no falling-off on these days in the performance of the test. This is most noticeable at the second period when the subject's condition was especially poor. So, too, the bulletins of A11 revealed feelings of being "below par" on certain days during the menstrual flow, on which, nevertheless, no lowering in performance could be detected in the records of either test.

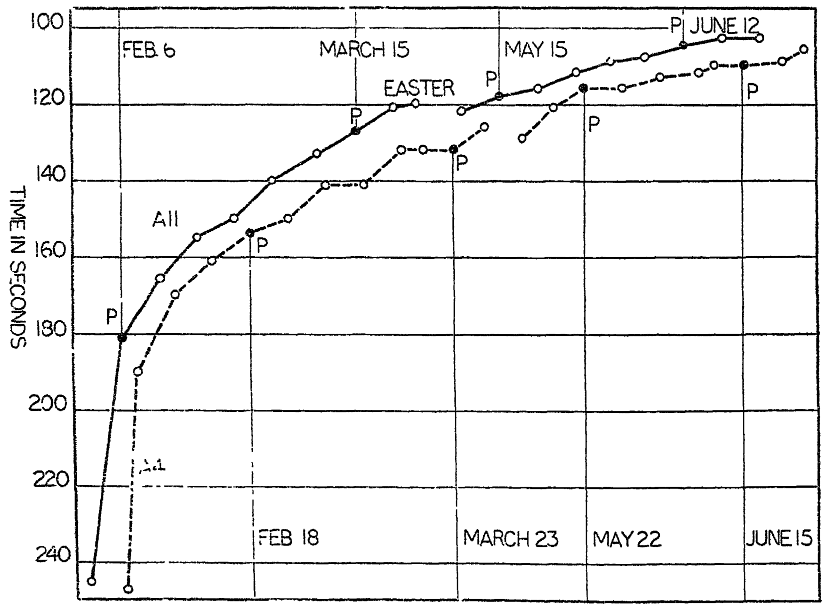

Fig. 15. Number-checking.

A7, A13, and B2 (*see* Tables) offer further examples of a practice curve in the number-checking test, undisturbed by any obvious influence of the menstrual period. A7 and A13 were healthy, bright and active girls. The dotting curve of B2 (*see* Tables) shows wide fluctuations which are probably due to the undoubted feeling of boredom produced (solely) in this subject by this test. She was a capable, reserved, self-centred girl engaged in clerical work.

5. Uncertain or Difficult Cases.

There is no clear evidence (*see* Tables) of the influence of menstruation on number-checking in the case of B5, an intelligent, refined, nervous girl, whose inter-menstrual intervals varied from 30—42 days and who complained of considerable discomfort and " nerviness " before her periods began, or when menstruation was delayed. On several such occasions she was forced to rest or to absent herself from work. In the dotting test (*see* Tables), however, the disturbing effect of these delays is perhaps noticeable. It is curious to find that this subject regarded the tests as helpful in controlling herself on her " off " days and that she regretted their discontinuance on this account.

In the case of A2, a quiet " average " girl, the spearing test was poorly done and showed such wide fluctuations from day to day that it was impossible to be certain of any influence of the menstrual period on efficiency. But when her performance of the number-checking test (*see* Tables) is considered, the data suggest a deleterious effect at or just before the onset of menstruation. With the exception of one day, she invariably described herself in her daily bulletin as " fit " (F).

In some of the subjects, the results are complicated by ill-health. A5 is a case in point. This girl was nervous, slept badly and occasionally walked in her sleep; at times she suffered from complete loss of appetite. The daily data of number-checking are very irregular, and are broken by short absences due to ill-health. Two of the four menstrual periods recorded show a depression; the first of these is strongly marked and may well be a true menstrual effect; but it is quite conceivable that such effect may have been aggravated by the bad state of the subject's general health. Her bulletins rarely record " fitness "; she was more often " fairly fit " or " a little tired," and sometimes " very tired." It is interesting to note that these depressions at the menstrual periods do not appear in the record of spearing (*see* Tables), a test which the subject said that she did with much ease; she played games well like the other adepts at spearing (*cf.* p. 28).

Another subject whose health was unsatisfactory is A9. She was always ailing; there was no single day throughout the two terms' work when the bulletin recorded her as " fit." She suffered from colds, headache, rheumatism, and other ills. She was,

however, very keen on the tests. Five menstrual periods are recorded, of which the second, third and fouth show depressions in the compressed curve for checking (*see* Tables); but other depressions, nearly as great or even greater, occur at intervening times. In the spearing test (*see* Tables) the variations during the periods are even less definite, the composite curve showing brief undulations throughout. She found that this test required much less effort than the number-checking test.

6. Subjects Wholly Omitted from Consideration.

A6 was also a subject whose health was uncertain. During the first term her records were interrupted by a bad attack of influenza, and again by absence during convalescence, on her return from which her bulletin records " very tired " for five consecutive days This subject, aged 29, came from overseas, and said that on first arriving in England she suffered from persistent amenorrhœa, for which she consulted a doctor. He attributed her condition to change of climate and anxiety. The news she received from home was often disquieting, and she came to dread each mail day; her worst score in the spearing test (13th June) was on such a day, when her bulletin recorded " very tired." The irregularity of her records does not permit of their being treated in the same way as those of other subjects. The simple curve shows that in at least three of the four cycles recorded " P " has no effect in comparison with the variations on non " P " days, due to other causes. The period days show some depression in the last cycle; but in view of the very large " chance " variations occuring in the records, their significance is extremely doubtful.

Similar gross irregularities in daily performance, which make it impossible to detect any influence of menstruation on efficiency occur in the case of B12, a capable and apparently healthy girl who carried out only the dotting test, and in the case of B13, a keen, highly skilled and dexterous worker, whose daily variations in performance of the same test during the inter-menstrual intervals were likewise so great that it was doubtful whether the " P " day depressions could be ascribed to the influence of menstruation.

Finally, absences through illness, or the paucity of menstrual periods due to temporary amenorrhœa, made it impossible to arrive at any conclusion in the case of A3, A12, B10 and B14.

7. The Subjects' Feelings of Fitness.

No correlations of significance were obtained between the feelings of fitness daily recorded by any of the subjects in their bulletins and their daily performance at the tests. In some subjects, or in the same subject at certain times, the feeling of unfitness might apparently stimulate them to do better at the tests, whereas in other subjects, or in the same subject at other times, it might be manifest in lessened efficiency. Some interesting results, however, arise when we consider the relation of such feelings to performance during the menstrual periods.

In thus dealing with the daily bulletins, it was found desirable to group the subjects' accounts of their general condition under two heads—" fitness " and " below par." This was due to the fact that certain subjects, especially those of group B, were often puzzled as to the exact heading under which they should record any feelings of unfitness—whether they should style themselves as "fairly fit" or "a little tired" or as "a little tired" or "very tired." All three descriptions were therefore grouped under "below par" (B), while good health is assumed to be indicated by "fitness" (F).

If we thus compare (*a*) the five subjects who most definitely show no effect of the menstrual period with (*b*), those who most definitely show an adverse effect of the menstrual period on the performance of the tests, we obtain the following tables showing the number of days of occurrence of F and B:—

(*a*) *Subjects showing no effect of the Menstrual Period.*

Subject	During Menstruation.		At other Times.	
	F.	B	F.	B.
A4	7	9	44	32
A7	2	11	19	41
A11	7	12	51	15
A13	10	3	46	32
B2	8	15	90	21
Total	34	50	250	141
Omitting A7 ..	32	39	231	100

(*b*) *Subjects showing adverse effect of the Menstrual Period.*

Subject	During Menstruation.		At other Times.	
	F.	B.	F.	B.
B3	5	10	91	30
B4	0	21	88	23
B6	2	19	100	17
B7	3	12	69	46
B16	17	2	115	17
Total	27	64	463	133
Omitting B16 ..	10	62	348	116

Whether or not the exceptional case in each of these two groups is omitted, the same conclusions are reached, namely, that in both groups most days of the menstrual period are

accompanied by a condition of feeling " below par," whereas on other days " fitness " is the more usual condition. But the frequency of being " below par " during menstruation is far greater among those who at that time fare worse at the tests. That this is not due to any greater general tendency among the A subjects, the University students, to consider themselves as really " fit " than among the B subjects, who were engaged in factory work, is clearly shown by the proportionally far greater number of records of " fitness " in relation to those of being " below par " among the second group (*b*), as compared with the first group (*a*) in the above tables, at other times than during the menstrual period. We may, therefore, on the contrary, with good reason suspect that the B group tended more often than the A group to style themselves as perfectly " fit " (F).

Let us finally turn to the third group of girls :—

(*c*) *Subjects showing favourable effect of the Menstrual Period.*

Subject.	During Menstruation. F.	During Menstruation. B.	At other Times. F.	At other Times. B.
A8	7	4	24	59
A10	14	3	67	0
B8	6	11	53	45
B9	26	14	157	19
B15	3	10	91	33
Total	56	42	392	156
Omitting B8 and B15	47	21	Omitting A8 ..368	97

The striking difference between this and the two preceding tables is that there are more " fit " days than " below par " days during menstruation. This comes out even more clearly when the subjects B8 and B15 are excluded. These are not quite comparable with the rest, inasmuch as B8 only showed increased efficiency during the later, not during the earlier part of the investigation (*see* page 27), and B15 only showed it as an after-reaction to a pre-menstrual fall in efficiency (page 24). A further characteristic (save for the Subject A8) is the relatively large number of days at other times than during the menstrual period on which " fitness " is recorded.

Comparing the three tables, we come to the broad conclusion that in regard to the frequency of their feeling of fitness at the menstrual period, those who do as well at the tests during the menstrual period as at other times stand midway between those who do better and those who do worse at the tests during that period.

VIII.—SUMMARY AND CONCLUSIONS.

1. Three tests were employed in this research—the number-checking, the spearing and the dotting tests (pp. 3–7). Each subject recorded her daily condition of health (pp. 7, 8). Two groups of subjects were tested daily over a period varying from four to six months—(i) a group of thirteen women who were University students mostly of about 22 years of age, and (ii) a group of sixteen women, employed by a firm of scientific instrument makers, whose ages lay between 17 and 28 years (pp. 8-10.)

2. Of these twenty-nine subjects, four had to be left out of account owing to the insufficient data which they provided; two showed such gross irregularities of performance that their data were also valueless for the purposes of this inquiry; and the records of one were so markedly influenced by ill-health and amenorrhoea, that here again no use could be made of them (p. 30).

3. Deducting these seven subjects, we are left with twenty-two. Of these (*a*) five showed no alteration in performance at the menstrual periods; (*b*) four[1] showed a better performance; (*c*) nine[2] showed a worse performance at these times or just before them; while (*d*) four showed a better or worse performance according to their stage of familiarity with the tests. Among the subjects of groups (*b*) and (*c*), the difference was found to be statistically significant in one subject of each group (p. 15).[3]

(*a*) The five subjects whose performance at the tests was *uninfluenced* by menstruation belonged, with one exception, to the group of University students, not to that of the work-girls. The four University students were all bright, cheerful, healthy, energetic girls. The work-girl was described as reserved, self-centred and capable (pp. 28, 29).

It is difficult—especially in view also of (*c*) (see next page)—to reach any other conclusion than that social status plays at present an important part in determining the effect of menstruation on efficiency. How far tradition, education and nutrition enter in this connection must be left to future investigation[4] (*cf.* page 9).

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[1] One subject (B8) is omitted from this group, as she only showed a better performance during the later stages of the investigation (*cf* p. 27). She is included in group (d) instead

[2] Including two somewhat uncertain cases and two complicated by ill-health (pp 29, 30).

[3] It may prove important to compare the results with those reached by T. Malamud (*C. R. de la Soc. de Biol.*, April 3, 1924, p. 26), who has investigated variations in the calcium content of the blood during the menstrual cycle. Of fourteen cases studied, she found an increase in the calcium content in 8, a decrease in 2, and no change in 4 women, during the menstrual period.

[4] A similar conclusion was reached by Catherine Chisholm, in her inquiry into bodily disturbances during the menstrual period. Among 500 secondary school girls, she found such disturbances in 41·75 per cent. (severe disturbances only in 7·8 per cent.); whereas among women workers the percentage rose to 76, and even to 84 when cases of slight or brief pain were included. ("Practitioners' Encyclopedia of Midwifery and the Diseases of Women," London, 1921, pp 763–767).

(*b*) The four subjects who showed better performances of the tests during menstruation are described as "bright," "mentally and physically strong," or as having "good physique"; and all (with one exception) recorded on a large proportion of days the feeling of fitness. One girl is characterised as "original," another as "artistic." Of a third it is reported that she consciously tried to resist the depression which she occasionally felt at the menstrual period (pp. 23–25).

(*b*) and (*d*) There were, in addition, three girls who performed the tests better at their monthly periods only during the early stages of practice, when novelty and interest doubtless influenced them; of these, two were described as "sensitive, impressionable and refined girls" while the third showed a strong desire to do well at the tests. Finally, there was a girl who performed the tests better after the initial period, perhaps of anxiety, had worn off (pp. 25–28).

We may perhaps conclude that when we meet with increased efficiency during menstruation, it occurs in rather highly strung, subjects of good physique, and that it is due to the play of such conscious or unconscious factors as tend temporarily to increased excitability or to the liberation of reserve forces which would normally be kept in reserve.

(*c*) Of the nine girls who showed *reduced efficiency* during or just before the menstrual periods, the performances of two girls were complicated by persistent ill-health (pp. 29, 30). Omitting these two cases, and bearing in mind the somewhat uncertain nature of the conclusions to be derived from two others (page 29), we are left with *no* cases among the A group, the group of College Students, and with *five* definite cases all among the B group, the group of factory employees. Of these one was a capable, delicate, uncomplaining girl, frequently suffering from coughs and colds and suspected of incipient tuberculosis. Another was of a homely,

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[1] In connection with these results, it is interesting to compare this increase of output during menstruation with three instances of heightened psychological activity observed elsewhere.

In the published letters of Olive Schreiner, she says, with reference to the menstrual period, "The time of greatest and most wonderful mental activity is just after, and perhaps the last two days of the time too. I was unwell last week, and now, though my chest is so troublesome, I can lie on the sofa half asleep and the thoughts are continually crowding in on me" (p. 31).

A young artist remarked to one of us with reference to her menstrual periods, "That is the time when the ideas come."

Another instance is that of an able woman, who told one of us tha at a time when she was engaged in designing, she noticed that at the onset of her periods she felt very much "alive," ideas coming quickly, and the work going with great ease. She would then have two days of depression, after which she was again very much "alive."

communicative disposition, who manifestly suffered pain or discomfort during menstruation, complaining that her " brain was not clear," and occasionally subject to bleeding from the nose at that time. A third girl, on the other hand, was bright and capable ; while the two remaining girls appeared to have psychoneurotic tendencies, the former being " delicately made," " lively," " excitable " and " irritable " at times, the latter although healthy to outward appearance, complaining of unaccountable fears when she rose in the morning (pp. 20–23).

(*c*) and (*d*). Finally we have to re-consider—as under the previous joint heading (*b*) and (*d*)—the three subjects (two of them " sensitive " and " impressionable ") who showed a lowering of efficiency during menstruation after they had become practised at the tests, *i.e.* (presumably) after their feelings of novelty and interest had worn off ; and one girl whose efficiency at the tests was reduced during menstruation only in the early stages of practice, when, conceivably, there was anxiety and nervousness in relation to the tests (pp. 25-28).

4. Comparing the five girls, who showed *no* effect of the menstrual period, with the five girls, who showed an *adverse* effect of the menstrual period on the performance of the tests, we find (i) that the former group record much less frequently than the latter a feeling of being " below par " during the menstrual periods, and (ii) that the latter group record more frequently than the former a feeling of " fitness " at times other than the menstrual period (pp. 30–32)

5. No correlation was found in individual cases between the daily feelings of fitness (or unfitness) and the degree of daily efficiency in carrying out the tests, although the latter sensitively revealed such temporary illnesses as colds, etc. (pp. 18, 30)

6. Any lowering of efficiency at the tests which occurred at or near the menstrual period was not in general greater than that which occurred at other times. That is to say, no experimental evidence was obtainable that the menstrual period in normal women is associated with serious incapacity for mental or muscular work (page 16).

7. The influence of the menstrual cycle on efficiency is not confined to the menstrual period. It may appear during the post-menstrual, and especially during the pre-menstrual period. There is also an indication of some influence at about the middle of the inter-menstrual period (pp 16,17, 21).

8. In all but one of those subjects to whom different instructions were given at different times, their scores in the (modified) number-checking test were found to depend on the pleasure or displeasure derived from the particular manner in which they were directed to mark particular figures (Appendix).

TABLES.

The figures in the following tables give the data for drawing the "compressed curves" (see p. 10). The figures in clarendon type relate to the menstrual periods, and the small index figures show the duration in days of each period. Sundays are omitted The methods of scoring are described on pp. 3–7.

TABLE A.—*Number-checking Test* (*Original Form*).

A 1	A 2	A 4	A 5	A 7	A 8	A 9	A 10	A 11	A 13	B 1
229	225	247	247	279	**256**^{4}	305	281	245	258	126
219^{2}	219	190	231	**260**^{3}	237	**253**^{2}	220	**181**^{5}	225	123
216	205	170	**242**^{4}	249	220	233	203	166	**204**^{2}	**122**^{3}
209	205	161	219	245	215	235	**193**^{4}	155	202	120
208	**199**^{3}	**154**^{5}	225	232	216	224	169	150	195	120
198	200	150	—	224	212	209	165	140	187	120
190	186	141	213	**228**^{4}	211	**219**^{4}	162	133	184	—
195	182	141	216	215	**206**^{4}	228	**146**^{5}	**127**^{5}	186	121
195	196	132	—	211	212	202	162	121	182	118
194	189	132	217	206	200	195	150	120	178	116
197	188	**132**^{4}	**212**^{3}	210	208	188	—	—	**175**^{4}	**118**^{3}
187^{2}	190	126	200	—	208	**204**^{3}	156	122	167	116
201	189	—	205	**204**^{4}	—	196	**163**^{3}	**118**^{5}	169	115
194	**192**^{2}	129	205	204	208	—	156	116	—	117
190	187	121	200	200	187	177	149	112	**175**^{4}	115
185	182	—	—	193	201	179	149	109	174	109
181	—	**116**^{4}	183	189	201	**188**^{3}	151	108	170	110
189	177	116	**190**^{4}	**189**^{6}	210	178	**143**^{3}	**105**^{5}	172	110
194	179	113	181	186	**182**^{6}	170	142	103	171	**112**
190	178	112	180	184	174	176	136	103	163	112
189	161	110	191	173	162	167	131		**159**^{3}	111
190^{2}	**173**^{3}	**110**^{4}	197	175	165	**166**^{4}	130		149	112
—	168	109	199			163			150	113
175	160	106	196			161			149	110
177^{2}	159		**192**^{1}			159			146	111
171	164		*			158			147	108
170	156		185							—
168	156		185							109
164	152									109
172	155									110
157	—									107
170	159									108
166	149									106
165										105
174^{2}										**107**^{4}
154										105
159										
155										
158										
156										
159										
149										
152										
150										
162^{2}			* Ill 5 days.							

TABLE B.—*Number-checking Test (Modified Form).*

B 1	B 2	B 3	B 4	B 5	B 6	B 7	B 8	B 9	B 11
135	249	242	291	268	268	242	206	218	241
122[3]	**214**[4]	**221**[4]	**304**[3]	**259**[6]	239	227	186	**205**[6]	251
199	207	206	271	235	227	228	184	211	**233**[2]
198	203	201	276	234	220	**231**[2]	**187**[4]	199	236
189	191	194	273	214	197	220	178	188	216
189	196	184	267	**214**[5]	**213**[2]	227	175	186	205
181	**187**[4]	179	276	199	200	211	171	**176**[4]	208
183	184	**186**[3]	**271**[4]	203	203	203	162	—	198
168[4]	182	180	248	199	194	205	**166**[4]	174	206
178	174	176	260	188	188	187	156	168	**196**[4]
176	174	171	240	180	183	199	153	166	189
170	166	177	247	—	184	**206**[2]	147	156	190
163	**166**[4]	174	241	**187**[5]	**186**[4]	192	142	148	185
165	163	**168**[5]	**242**[4]	180	179	183	151	**153**[5]	184
156	156	163	233	176	178	*	**145**[3]	155	173
152[3]	152	160	225	156	173	201	—	149	**172**[3]
143	156	—	220	160	159	189	149	153	172
153	**151**[5]	166	216	**152**[6]	**162**[4]	178	148	**144**[5]	169
—	—	**157**[4]	—	151	—	**174**[3]	142	142	170
142	144	146	219	153	154	169	136	141	—
146	149	149	**227**[3]	154	161	173	132	139	171
140	145	146	210	150	149	—	**129**[2]	134	168
138	**140**[3]	139	218	**149**[4]	152	165	129	136	167
137[3]	138	141	221	146	**147**[3]	163	140	**127**[1]	**164**
129	138	**140**[4]	213	141	152	162	134		170
132	131	134	203	140	149	**151**[3]	133		185
131	126	136	208		139	148	132		173
129	**127**[3]	133	**203**[3]		146	140	130		171
135	127	127	206		147	136	**131**[3]		169
127	131	125	209		**141**[4]	133	127		**182**[4]
136[3]	127	126	198		138	135	135		173
125	127	**128**[3]	205		142	129	136		169
122	128	122	210		138	128	137		167
130	**122**[4]	129	202		134	**123**[3]	131		169
122	126	126	**205**[4]		135	130	131		165
123	118	124	205		**139**[4]	128	126		159[1]
122	123	125	197		137	123	†		**165**
119	*		193		132	124	126		157
120[3]	128		—		133	125			159
119			203		135	121			161
115			203			122			161
117						126			155
115						**124**[3]			
						121	† Away ill two weeks.		
						124			
						121			
						120			
	* Away ill 5 days.					* Away ill one week.			

TABLE C.—*Spearing Test.*

A 1	A 2	A 4	A 5	A 7	A 8	A 9	A 10	A 11	A 13
218	183	231	220	201	**203**[5]	204	221	210	220
229	194	243	227	219	214	**234**[2]	229	**235**[5]	217
230	205	257	225	**216**[4]	226	235	215	250	**214**[2]
228	209	252	**241**[4]	232	225	211	**231**[5]	242	230
233[2]	216	**253**[5]	240	221	211	212	229	237	229
226	**211**[3]	250	232	228	218	207	221	245	214
214	198	249	—	224	225	**210**[4]	224	234	220
212	218	254	239	**224**[4]	**224**[4]	213	**218**[5]	**232**[5]	210
219	213	253	238	225	219	224	209	233	211
227	213	255	—	220	228	217	219	236	212
236	205	**258**[3]	230	220	213	219	—	—	**217**[4]
228	197	256	**233**[3]	216	216	**222**[3]	227	239	221
234	214	—	237	—	—	210	**225**[3]	**239**[5]	—
223	204	253	244	**213**[3]	221	—	219	233	**225**[4]
235[2]	**212**[3]	254	237	209	219	222	218	241	224
221	212	**240**[4]	235	207	193	**217**[3]	225	247	227
223	224	258	—	219	216	221	225	253	220
235	—	258	236	226	198	234	**215**[3]	**254**[5]	226
227	223	258	**236**[4]	**220**[6]	**213**[5]	226	229	248	225
230	198	261	225	219	219	232	219	243	**223**[3]
234	201	**260**[4]	239	220	222	**225**[4]	234		232
242	192	257	231	224	214	234	224		224
230	**201**[3]	265	247	216		224			230
243	212		228			239			234
225[2]	215		236			227			
236	200		**234**[1]						
230	201		*						
—	212		239						
226	220		243						
227[2]	210								
233	207								
228	212								
224	217								
220			*Away five days (influenza)						
221									
227									
223									
234									
233									
220[2]									
242									
242									
227									
234									
237									
238									
243									
229									
245									
235[2]									

TABLE D.—*Dotting Test.*

B 2	B 3	B 4	B 5	B 6	B 9	B 12	B 13	B 15	B 16
53	49	134	33	**21**^{4}	49	21	20	**47**^{3}	7
50	**28**^{5}*	133	31	16	41	19	24	55	16
49	33	112	29	21	**36**^{4}	36	24	71	13
65	60	116	31	21	53	13	17	45	**7**^{2}
39	64*	126	51	26	46	22	**45**^{2}	41	9
39^2	53	79	49	16	33	24	*	41	8
46	†	**151**^{2}	**44**^{4}	36	36	**44**^{3}	31	33	5
70	43	91	24	**36**^{5}	38	37	26	39	10
39	**43***	91	33	28	**29**^{4}	18	42	54	20
46	66	76	21	33	42	45	46	**52**^{4}	15
34	47	68	24	42	41	48	30	45	**18**^{3}
42	47	48	—	32	42	42	31	30	16
57^2	53	61	40	**31**^{4}	29	36	**34**^{2}	34	14
52	**60**^{3}	**116**^{3}	36	23	35	24	25	47	15
97	40	78	37	30	—	17	32	**34**^{4}	19
65	—	92	**47**^{3}	31	24	**21**^{2}	37	52	25
72	33	76	33	27	27	23	24	47	23
61	36	75	33	**27**^{4}	29	26	51	47	21
41	41	90	37	22	34	54	54	42	**28**^{3}
81^1	35	101	18	—	29	40	43	57	32
116	**34**^{4}	—	20	24	**19**^{5}	22	**54**^{3}	—	‡
58	40	112	—	33	16	40	37	**89**^{2}	15
43	30	68	**17**^{2}	**19**^{5}	15	48	31	67	28
79	29	76	19	17	22	**23**^{4}	—	53	26
35	51	72	23	18	26	34	20	42	16
66	33	67	21	19	—	—	21	45	17
51	**32**^{3}	**137**^{3}	19	26	9	21	30	37	17
—	29	72	15	**24**^{5}	**9**^{3}	24	30	27	15
67	38	42	12	14	9	24	§	29	**19**^{3}
59	27	66	18	—	9	**39**^{2}		34	17
26	39	64	**21**^{5}	27	8	21		38	19
61^2	25	63	8	26	†	—		19	26
29	17		—	22		13		22	20
45	35		11	**23**^{3}		11		**28**^{3}	14
35	**27**^{4}*		**12**^{6}	18		19		36	**24**^{3}
17	18		7	19		20		38	8
24	24		6	16		**23**^{3}		21	21
21	26		9	11		20		40	14
24	21		8	17		12		38	12
23^2	31		12	7		—		35	14
34	27		12	**13**^{2}		20		24	14
—			**6**^{3}	14		39		**15**^{4}	11
45			10	14		20		22	12
32				17		16		20	**10**^{3}
34				14		27		10	12
37				14		33		16	21
36^2				24		**16**^{2}			14
40				**12**^{3}		9		9	14
34				12		11			14
33						18			21
38						11			12
31						8			**12**^{3}
40						6			16
17^2						12			
38						13			
46						**17**^{3}			
30						27			
—						22			
37						—			
58						10			
59									
80^3									
47									
43									
	* Bad cold. † Away with influenza.				† Left to be married.		* Away ill four days. § Left to be married		‡ Away 26 days with septic foot.

APPENDIX.

The Influence of Affective States on Number-checking.

The number-checking test (modified form) had been in use with the subjects of Group B for many weeks, when an opportunity occurred for giving this, among other tests, to a University graduate, whom we will will call "X." He expressed a wish to see the working of some of the tests in use in the laboratory, and kindly offered himself as subject. On every day for some weeks he went through the number-checking test.

It was surprising to find that an exercise, apparently so unexciting, aroused in this subject quite a strong feeling-tone, which, according as it was agreeable or otherwise, produced well-marked effects upon his performance "X" explained that he had long had what he termed a "number complex," that he worked out all the affairs of life in percentages, that five was to him a very important digit, and that its appropriate mark was obviously the circle. He liked sheet 3 (ii) (*see* p 5), because in it the directions call for "circle round 5," cross-stroke through 3, and down-stroke through 6 Sheet 1 (i) also gave him pleasure, he said, since here again the circle goes round the 5. He disapproved of encircling a 6, and consequently sheet 2 (i) aroused particular dislike; next to that he most disliked 2 (ii).

In Fig. 16, the result of this affective factor is shown by plotting as curves the scores of the two best-liked parts and also those of the two parts most disliked. It is seen that the curve for the favourite part rises far above that liked next best, while this latter in turn is much higher than the curves of the two parts most disliked. These two last are not well separated, but cross and re-cross each other several times.

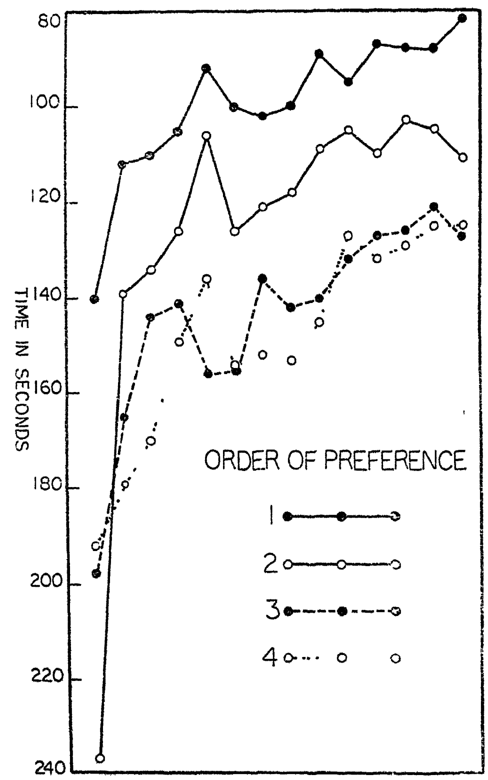

Fig. 16.

Such results obtained from "X" naturally raised the question as to whether any similar affective factor entered into the performances of the girls of group B, who were then being tested. It had been previously noticed that pronounced changes of attitude towards the tests occasionally occurred among them. A subject would say, for instance, "Oh, this is different, is it not?", or, "We have not had this often before, have we?", the remark being made apparently rather by way of apology when the subject thought that she had been rather slow over the test. Of course, no information was ever given in answer to such remarks. But it was easy to encourage such conversations, and illuminating remarks about feelings were soon obtained without the possibility of any suggestion having been aroused.

Of the 11 subjects in this group who carried out the number-checking test, one girl had no preferences whatever; but in the remaining ten the affective factor entered to a variable extent into their performances. These subjects of course were not so expert in introspection as "X"; neither they nor their experimenter ever spoke of a "complex." But they tried their best to explain why they liked or disliked a test, and it was amusing to watch how sometimes their explanation took on an almost ethical character. For example, a subject would say, "No, I do not like it; I think the circle 'ought' to go round" such or such a digit One of the girls, B4, would sometimes exclaim "lovely," when she found that the sheet 2 (i) gave the directions which she liked, but, as a rule, the feeling-tone was not as strongly marked in any girls of group B as it was in "X."

Two further graphs (Fig. 17) are given which illustrate the play of this affective factor in this group. They were obtained from the subjects B1, B2. Other graphs, identical with these, were prepared from the records of B4, B5, B7 and B8, but it seems unnecessary to publish these.

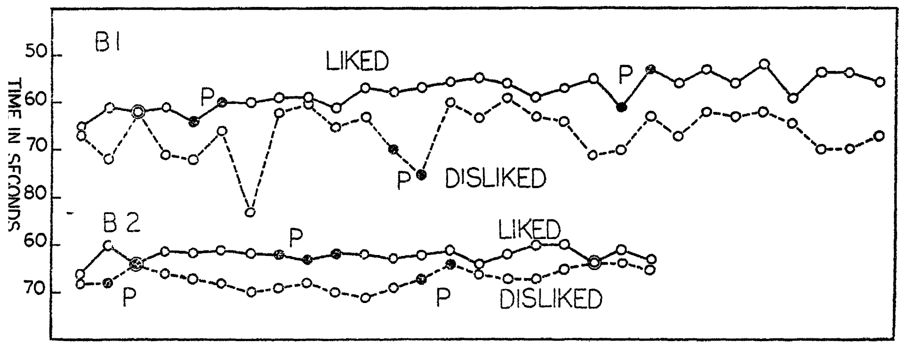

FIG. 17.

However interesting, from the psychological point of view, this curious feeling about numbers[1] is somewhat embarrassing in regard to the present purposes of the data here collected. The opposite feelings of "like" and "dislike" would probably balance each other to a certain extent "in

[1] It is interesting to hear from Mr Udny Yule, to whom the curves of "X" were shown that, in dealing with statistics on a large scale, he has likewise come across a kind of favouritism in regard to numbers somewhat similar to the like-dislike factor here noted; but, apparently, in the instances observed by him, the "feeling" was quite unconscious. A paper by Minot, "The Number Habit," *Proc. American Society for Psychological Research*, Vol. 1, Part 2, 1886, deals with a similar phenomenon.

the long run," although the "like" would appear to be the stronger factor of the two. But as there was no means of knowing how to allow for its influence, it was felt that, in view of the uncertainty introduced by this affective factor, it would be advisable to abandon this "modified" form of the test and to substitute some other test In dotting, it was thought, there could hardly be latent such possibilities of affect as had emerged with disconcerting emphasis in the revised form of number-checking test, and it was hoped that the practice effect would be short-lasting. In this last respect there was some disappointment; improvement by practice continued for many weeks.

II. THE RELATION OF THE MENSTRUAL CYCLE TO GENERAL FUNCTIONAL ACTIVITY.

By E. M. BEDALE, M.A.

CONTENTS.

INTRODUCTION.

It has often been alleged that women are greatly and unavoidably handicapped in professional and business life by physiological and psychological instability, said to be the natural consequence of a conspicuous monthly rhythm to which all their functions are subject. At the present time, also, attention is being directed to the incidence of menstrual disorders and discomforts among women in industry, and there is a tendency in some quarters to stress the economic loss and personal suffering which arise from such causes, and to advocate special measures of regular relief as part of the welfare arrangements of factories. On the other hand, there is a strong body of opinion which claims to have shown by experience with girls and young women, that dysmenorrhea is rare, and that, when present, it can generally be cured by simple hygienic measures and by encouraging an attitude of healthy-minded indifference to the matter.

The supposed rhythm in functional activity has naturally aroused some interest among physiologists, and from time to time, observations have been made. The evidence is conflicting. Some workers find a marked rhythm, others none at all. If the original publications are read, it is impossible not to perceive that, in some cases, the observers were biassed in one direction or the other. There is also a certain amount of evidence of a quite indefinite character, suggesting, on the whole, that if there is any functional periodicity, it is of a small order.

The present work was undertaken in the hope of throwing further light upon the vexed questions of the existence and practical importance of the supposed periodic rhythm. In particular, an attempt was made to ascertain whether the performance of physical work during normal menstruation occasioned any peculiar physiological costs or reactions.*

Plan of the Present Work.

In the present work, a three months' study was made of some aspects of the functional activity of a single subject, under conditions as closely controlled as possible. It was hoped that by fixing the diet, exercise, and hours of sleep, and by taking daily observations at the same hour and under uniform conditions, the usual variations of physiological behaviour would be so far reduced as to show the presence or absence of a monthly rhythm more clearly than can be the case where the many variables of ordinary life have full effect.

Observations were made (*a*) of the body temperature, twice in twenty-four hours; (*b*) of the basal metabolism, together with pulse rate, blood-pressure, and respiration rate in the post-absorptive resting condition; (*c*) of the vital capacity; (*d*) of the metabolic cost of performing measured work on an ergometer, with the reaction of this work upon the pulse rate, blood pressure and respiration; (*e*) of capacity for maximal exertion in working the ergometer as fast as possible for five minutes again, with the effects of this on the circulatory and respiratory functions.

The diet was of a gross value of 2,700 cals., selected and modified experimentally before the work began. Including one egg, one pint of milk, one ounce of cheese, four ounces of fresh beef steak (grilled) and a generous ration of fruit, it was well balanced and contained all essentials; it was also so simple that it did not become tedious. The body weight remained approximately constant throughout the whole experiment.

The hours of rising and going to bed were fixed, the exercise taken daily and the occupations of every part of the day were, approximately the same throughout the three months of the experiment. The few departures from routine which occurred—the performing of an hour's experimental muscular work in the afternoon, or going out in the evening, instead of reading at home—were arranged for the middle of inter-menstrual periods.

The subject (Ht. 176 cm., Wt. 54·5 kg., naked, Age 30) was a healthy woman, not muscular, and leading generally a sedentary life. Menstruation normally occurred every twenty-eight days, accompanied by some discomfort for a few hours, but not enough to interfere with the day's work. The subject's own estimate was that she was always below her best in physical energy at the period, but that for mental work she was not in the least disabled, though

* A review of previous work is given in Appendix II.

possibly rather more effort might be required to get started. Hollingworth's (3) point, that the subject should not be aware of the aim of the experiment, is a good one. The present subject knew the purpose of the work, but had no prejudices as to the result, except a purely academic one, that the basal metabolism might be associated with the well-established temperature rhythm. Perhaps, like most healthy women, she had the *wish* to disprove the supposed disabling effects of menstruation ; certainly there was no likelihood of voluntary slackening of effort at the periods. The observer did not know the purpose of the experiment, nor when the periods occurred, so that possible psychological influences, such as Hollingworth deprecates in Voitsechovsky's work, were minimized. The daily records were not examined nor compared until after the work was completed.

The three months' experiment, unfortunately, did not follow quite so smooth a course as was marked out for it. An anomaly arose in the second month, when the onset of menstruation was delayed eight days beyond the proper date. The subject had experienced some delay several times before, " when working very hard," but had been regular for several years before the experiment, and since There was no apparent disturbance, objective or subjective, connected with the prolonging of the inter-menstrual period, and the cause of it cannot be determined.

A second and perhaps more serious difficulty arose from the fact that the subject's general vigour seemed to deteriorate gradually from about the middle of the experiment. The progressive lowering of vitality, of which there is some evidence in the curves given later, may be part of a broad seasonal rhythm ; or it may indicate wholly or in part that cumulative effect on the organism of monotonous routine, which is typically exhibited in what is called " industrial fatigue." The subject did not admit to feeling the routine a strain ; she rather appreciated it as ensuring a morning's work without demand on initiative. Sleep was not impaired ; appetite was not very much affected, so that the full ration was still taken, and consequently the weight decreased hardly at all. Digestion was very good throughout. Yet the subject felt " rather tired all the time, inelastic in body and mind " ; and the quality of mental work (reading in the evenings) certainly deteriorated. Perhaps this accidental by-product of observations on mild progressive fatigue is not less interesting than such evidence as appears on the main problem of functional periodicity.

EXTENDED RESULTS

In the first part of this paper the circumstances in which the several observations were taken will be described, and the complete results for the three months will be given in graph form. In the second part the same results will be presented in the form of smoothed curves for one average cycle, in which accidental fluctuations largely cancel each other out.

Ninety-two consecutive daily determinations were made on the basal metabolism, with pulse rate, blood-pressure, and respiration rate. (September 19th–December 19th.) Eighty observations were made of the vital capacity. (October 1st–December 19th.) Seventy-nine determinations were made on working metabolism, maximal output of work, and effects of these on pulse rate, blood-pressure, and respiration rate. (October 2nd–December 19th.)

A. *The Body Temperature.*

The rectal temperature was taken at 7 a.m. and at midnight. The conditions in the morning were perfectly standardized, the temperature being taken (seven minutes) immediately on waking. The night conditions were hardly less stereotyped, for the subject had been sitting still in a warm room for several hours previously. On a few occasions in the last inter-menstrual period the night temperature was not taken until one to three hours later, but these temperatures are not appreciably lower than those taken strictly at midnight on the preceding and following nights; so that presumably the usual waking metabolism was fairly maintained until the subject went to bed.

The inter-menstrual rise of temperature, and the fall at menstruation, are very apparent in Fig. 1 A.

Fig. 2 presents the smoothed curve of the temperature wave, as reached by the statistical method described in the second part of this paper. It has a curious feature in the convergence of the morning and night temperatures from about the tenth to the fifteenth day, but the average of three cycles only is too slight a foundation for regarding the phenomenon as significant.

B. *The Basal Metabolism.*

The post-absorptive resting metabolism was determined by the Douglas-Haldane method at the same hour each morning. Previous activity was stereotyped (e.g., bath always of the same temperature) and was of a mild order, including fifteen minutes' quiet walk to the laboratory. The subject lay completely relaxed and still for thirty minutes before the determination was made. The laboratory was well and about evenly heated on all days except Sundays, when the temperature was often very low, and the subject had to be kept warm by several coverings. The Sundays are marked (S) in Fig. 1 B. It does not appear that any of the variations of metabolism can be definitely assigned to chemical heat regulation special to these occasions, for there are six instances where the metabolism is higher than on the preceding day, and six when it is lower.

In Table I and Fig. 1 B, the oxygen consumption per minute for each day is given. The determination for October 25th (an unimportant inter-menstrual day) was lost through trouble with the analysing apparatus. The value for October 10th, unfortunately, the first day of the first menstrual period, was vitiated by

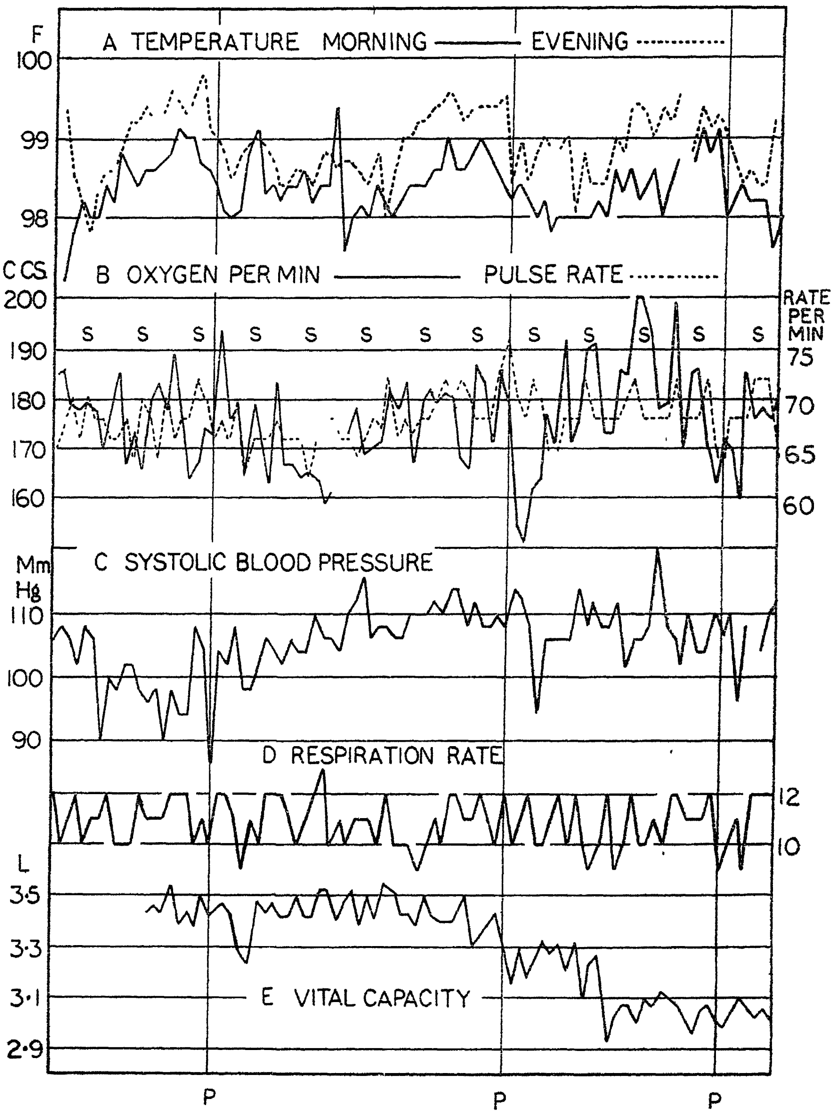

FIG. 1.—A Rectal temperature at 7 a m. and midnight. B. Basal metabolism and pulse rate. C. Systolic blood-pressure, resting. D. Respiration rate, resting. E. Vital capacity.

September 19th to December 19th.

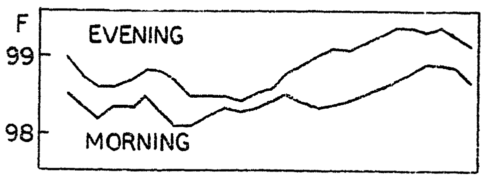

FIG. 2.—Temperature curve smoothed by superimposition of three cycles, 28 days from onset.

the fact that the subject was suffering from anxiety (which was relieved before the next day). Mental excitement may possibly have been a factor in the three very high values which occur early in December. On the whole, however, it is believed that psychological factors were kept fairly constant ; the subject read through a particular page of the newspaper daily, during the first half of the preliminary rest, and the laboratory was always empty and quite.

It will be seen from the table and figure that the variation in basal oxygen consumption was considerable, the average being 175·5 cm., standard deviation 9·7, coefficient of variation 5·5 per cent. The extremes are 151 cc. on the third day of the last menstruation, and 200 on the 16th and 17th days of the last cycle.

It seems, examining the curve of Fig. 1 B, that there is no clear rhythm corresponding with the menstrual cycle during the first two months. The metabolism falls frequently and apparently fortuitously below the line indicating 170 cc.O_2 per minute. If these low values represent chance variations of muscular tone connected with fatigue, weather, or subjective circumstances, they seem to be of no less degree than that reduction of metabolism

TABLE I.

Dates (inclusive).	Phase.	O_2 per minute.	Average.
Sept. 19–21 ..	Post-Mens.	185, 186, 179	183
Sept. 22–Oct. 4	Int.-Mens.	178, 179, 178, 170, 177, 185, 167, 173, 166, 180, 183, 178, 189.	177
Oct. 5–9 ..	Pre-Mens.	172, 164, 167, 174, 173..	170
Oct. 10–14 ..	Mens. ..	(194) 176, 178, 165, 179..	174
Oct. 15–19 ..	Post-Mens.	171, 163, 183, 167, 174..	172
Oct. 20–Nov. 10	Int.-Mens.	164, 165, 164, 159, 161—173, 178, 169, 170, 171, 182, 178, 183, 167, 180, 182, 179, 181, 180, 168, 166.	172
Nov. 11–15 ..	Pre-Mens.	187, 183, 171, 186, 179..	181
Nov. 16–20 ..	Mens. ..	154, 151, 162, 164, 177..	162
Nov. 21–25 ..	Post-Mens.	171, 192, 171, 175, 190..	180
Nov. 26–Dec. 7..	Int.-Mens.	200, 200, 193, 178, 179, 199, 170.	189
Dec. 8–12 ..	Pre-Mens.	185, 186, 170, 163, 172..	175
Dec. 13–17 ..	Mens. ..	170, 160, 185, 176, 178..	174
Dec. 18–19 ..	Post-Mens.	176, 182	179

about the time of menstruation which is, in fact, visible in the curve, and which, in theory, it is possible to postulate as the cause of the unquestionable drop in body temperature at this time. In the third month a cyclical rise and fall seems apparent, in spite of

the fact that in the inter-menstrual period the day to day variation is still often about 20 cc. per minute. While it is true that the subject was tiring and that mental states and the "stimulating (and otherwise) action of fatigue" may have exaggerated both the great menstrual fall (November 15th) and the subsequent inter-menstrual rise, these circumstances were certainly not sufficiently marked to render the subject's condition pathological, and, therefore, this indication of a cyclical wave in basal metabolism need not be rejected. The superimposition of the three cycles brings it out more clearly (see Part II). It may also be noted that the basal oxygen consumption is on the whole rather higher in the last month than previously. The fluctuations are at least as great, but the comparatively low level of 170 cc. 0_2 per minute is not touched during seventeen days in the last inter-menstrual period

It may be recalled that Palmer, Means and Gamble (38) give data for basal metabolism of one subject in winter and summer, which show that the winter metabolism was definitely higher, though the temperature of the immediate environment was much the same. These data are discussed in Benedict's (39) "Factors affecting basal metabolism."

C. *The Basal Pulse Rate.*

The pulse rate was counted during the collection of expired air for the basal metabolism determination. The curve of all the observations, Fig. 1 B, shows that a drop occurs at, or close to, each menstruation ; but that these are no more conspicuous than others, presumably of chance origin. It would not be possible to judge from the graph where the critical times fell, if no indication were given

Benedict and his co-workers (40) state that "there is a clearly established relationship between pulse rate and total metabolism. This, while being more marked in some individuals than others, is almost invariably observed." Speaking of observations on infants, who were often restless, Benedict and Talbot (41) say, "Whatever increases the pulse rate increases katabolism." It is certain that rises of pulse rate and of metabolism occasioned by exercise are constantly found together, though it may not be possible to establish any mathematical proportion between them. There is also the familiar fact of rapid pulse rate in febrile conditions, and on this ground the basal pulse rate would be expected to correspond with the periodic temperature wave in women. If a rhythm in basal metabolism can be demonstrated as part-cause of the temperature changes, the pulse should follow the same rhythm. But direct evidence in this field is indecisive. Zuntz (1) found periodic rhythm in pulse and none in metabolism. Blunt and Dye (16) found no definite constant change in either. Collett and Liljestrand (19) found periodicity in metabolism and a different and rather uncertain variation in pulse rate.

The new data here submitted are, unfortunately, equally uncertain and, to some extent, self-contradictory. Close examination of the pulse rate curve in Fig. 1 B shows that there is a quite distinct raising of the general level of pulse rate over the last weeks of the experiment, corresponding with rising trend of oxygen consumption already pointed out. As the pulse rate, and the basal metabolism, on a suitable scale, are plotted together, a correspondence of daily variations is apparent in many instances, but by no means universally. Finally, when the curves are smoothed by the superimposition of the three cycles (Part II), there appears actually to be an *inverse* variation of pulse with basal metabolism. (Fig. 4, p. 58.)

D. *The Blood-Pressure.*

The systolic blood-pressure was taken with an accurately calibrated Tycos sphygmomanometer, immediately after the basal respiratory sample was completed, and without disturbing the subject in any way. The data, represented in Fig. 1 C, are very inconclusive; there are dips at the first and third menstruations, but at the second there is no fall till three days after the onset; and none of these dips are greater than chance fluctuations. Superimposition of this curve on that for pulse rate does not demonstrate a daily correlation; there are instances of direct and of inverse variations in about equal numbers. There is, however, a definite rise in the general level of the blood-pressure from about the middle of November, parallel with rises in pulse rate and oxygen consumption.

E. *The Respiration Rate.*

The respiration rate was counted during the collection of the sample of expired air. (Fig. 1 D.)

F. *The Vital Capacity.**

The vital capacity was determined about ten minutes after the completion of the basal determinations. The subject had meanwhile been moving quietly about the laboratory, and was still fasting. The Boulitte spirometer was used, and the best of three expirations was taken as the day's value, the dial being invisible to the subject during the expiration. The subject was well accustomed to the procedure before the experiment started, so that there is no practise improvement in the curve of Fig. 1 E. The general level of the maximal output of the lungs during the first four or five weeks agrees well with sundry determinations made for this subject over the last three years. If 3·55 litres be accounted her utmost vital capacity (3·50–3·55 occurs ten times in the present series) this, with stem-height 87·6 cm.,

* The Vital Capacity is the maximum amount of air that can be expelled from the lungs in a forced expiration following a forced inspiration.

weight 54·5 kg. (12 per cent. below normal for her stem-height), chest circumference 76 cm. (normal for stem-height) would place the subject, according to Dreyer's Assessment of Physical Fitness, just into Class A. Her breathing conforms markedly to the abdominal type.

The most conspicuous feature of Fig. 1 E is the fall in maximal expiratory power through November to a general level during December, 400–500 cc. less than that prevalent at the beginning of the experiment. I do not think that this decrease in vital capacity can be attributed to psychological causes, to staleness or boredom with the routine. Throughout, great efforts were made to recover the original level and there was no corresponding subjective sense of incapacity, nor even any general sense of fatigue for at least two or three weeks after the deterioration in vital capacity had begun to show itself.

However the upward trend of basal metabolism, pulse and blood pressure may be interpreted, this change in vital capacity is unlikely to be a seasonal variation. It probably indicates a certain loss of physical fitness, not of a very serious order, not peculiar to this subject, nor, probably, a result of the routine of work and diet ; but the common lot of all who work in a difficult climate without much opportunity for open-air exercise, and who naturally lose vigour as the holiday month recedes. As a study in slight progressive fatigue, therefore, Fig. 1 E has a certain interest. The subject at the end was rather low in Dreyer's Class B, to which, as a sedentary worker, she properly belonged. It may be remarked that on December 19th, the last day of the experiment, the subject made several attempts to improve upon the morning figure, 3·01 litres, without success. A fortnight later, after a short holiday, about 3·43 litres was blown through the spirometer repeatedly.

Evidence for a monthly periodicity does not strike the eye in Fig. 1 E. It may be seen that the curve does, indeed, dip at or near each of the periods, but other dips also appear, and there is little suggestion of the crest of a pre-menstrual rise.

G. *The Cost of Performing Equal Rhythmical Work.*

In order to investigate whether or not menstruation affects the physiological cost of work, data were collected of the oxygen consumption, pulse rate, blood-pressure, and respiration rate during the performance of work at a fixed speed on the hand-lever ergometer.

This experiment was timed to begin between 12 p.m. and 12 15 p m., i.e. two and a-half hours after breakfast. The subject's activity during these intervening hours was closely similar from day to day, consisting chiefly of the usual more or less sedentary business of the laboratory. Time could not be spared for making a determination of the pre-work resting metabolism just before this work experiment, as is usually done. To get a net value for

working metabolism it is, therefore, necessary to subtract the true basal of the day. No great exception can be taken to this procedure, as the breakfast was identical and other conditions very similar. It is, of course, always possible that half an hour's previous rest might so have stabilized the organism as to have reduced somewhat the chance variations which appear in the working energy expenditure. However, a comparison of the pulse rate, sitting, just before beginning work, with the basal pulse taken at 9 a.m., shows so good a daily correspondence that this source of error may be regarded as small.

A light form of work was chosen, viz. a load of one kilogram and a metronome beat of 115 per minute, giving 210 kilogram-metres per minute. It was essential to the purpose that the tax on the muscles of the shoulders and arms should not be so great as to demand relief by other groups of muscles, as by "putting the back into the work," which would introduce such large and erratic variations of metabolic cost as assuredly to obscure any fundamental periodic change which might exist. The subject had to aim at keeping the trunk erect and still, the feet in the same position, the muscles of the legs and back in the same degree of tension; and at working the levers, from the arms and shoulders only, by a smooth movement equally compounded of thrust and pull. Such standardized conditions of the whole body might conceivably be achieved voluntarily and perfectly by a trained gymnast; the ordinary person can do little more than regulate negatively by seeing that no visible irregularity of position or movement is adopted, and then trusting that in the fifteen minutes of smooth mechanical work before the sample is taken, the whole organism will have settled down into its habitual working behaviour.

The variations which occur are, doubtless, due to accidents of general "condition" and vigour, and perhaps more particularly to variations in the state of the contraction of the various leg muscles, more largely than to diurnal differences in the condition and oxygen demand of the group of muscles directly involved in moving the levers. The oxidation due to the activity of such a group of muscles cannot be separated from that of the body as a whole, nor can that activity be very strictly confined to the muscles directly concerned; the data must, therefore, be regarded as some sort of index to the working exertion of the body as a whole.

For the whole seventy-nine experiments, October 2nd–December 19th the averages are as follows :—

TABLE II.

	Average. O_2 *per min.* cc.	*Standard dev.*	*C. of V. Per cent.*	*Kgm. per min.*	*Average.* O_2 *per Kgm.* cc.	*Average Mech. Eff.*
Gross ..	658·4	31·64	4·8	210	31·35	15·03
Net ..	482·6	32·19	6·7	210	22·99	20·39

The curve of daily values (net) is given in Fig. 3 A. While the day to day variations are of a large order, there is, perhaps, some slight indication of inter-menstrual rise, and menstrual fall. Since the external work performed per minute is always the same, this involves the rather paradoxical conclusion that the metabolic cost of work is *less*, the mechanical efficiency *higher*, during menstruation than at the crest of the wave, associated with a sense of well-being, in the inter-menstrual period. This rise and fall of costs is a shade more marked in the net than in the gross costs. As all extraneous movements were, as stated above, as far as possible eliminated, the explanation must be that the muscular tone of the whole body varies, and that when the tone is low, external work of this mild order can be performed at a lower metabolic level than it actually is at times of full vigour.

In this connection it is interesting to note that the effect of variations in the cooling power of the atmosphere seem to have been in the same direction—the reverse of what at first sight might have been expected. On about sixty days readings of the dry kata thermometer were taken during the performance of the work, a window and a door being open, except on very cold days, at opposite ends of the 40 ft. room. The readings vary between 8·5 or 9 millicalories per sq. cm. per second on Sundays, when the building was unheated, to as low as 5·5 on some very close days. When these points are plotted with the corresponding points for oxygen consumption (Fig. 3 A), there appears to be some degree of *direct* variation of metabolism with cooling power. Leonard Hill, indeed, finds that mechanical efficiency is not affected by cooling power in short experiments of 15 minutes' duration ("The Kata Thermometer in Studies of Body Heat and Efficiency," p. 171), yet from the general trend of his work, and from the subjective sensation of comfort when the heat loss by radiation and convection was high (wet Kata not being determined), an inverse rather than a direct variation of working metabolism with cooling power was expected.

No doubt this result was again due to the mild nature of the exercise and to its short duration, about 18 minutes. The subject, wearing light comfortable clothes, with neck and forearms exposed, was hardly heated to the extent of sensible perspiration, so that cooling power was not of such primary importance as in more strenuous work. Bracing atmospheric conditions apparently heightened the muscular tone and so tended to increase slightly the objective costs of work.

The Pulse Rate during Ergometer Experiments.

The pulse rate was counted before work began, the subject sitting still on the stool of the ergometer. It was also counted by stethoscope on the carotid in the sixteenth minute of the work, and again, between the forty-fifth and sixtieth seconds after the cessation of work. The second of these curves is given in Fig. 3 B.

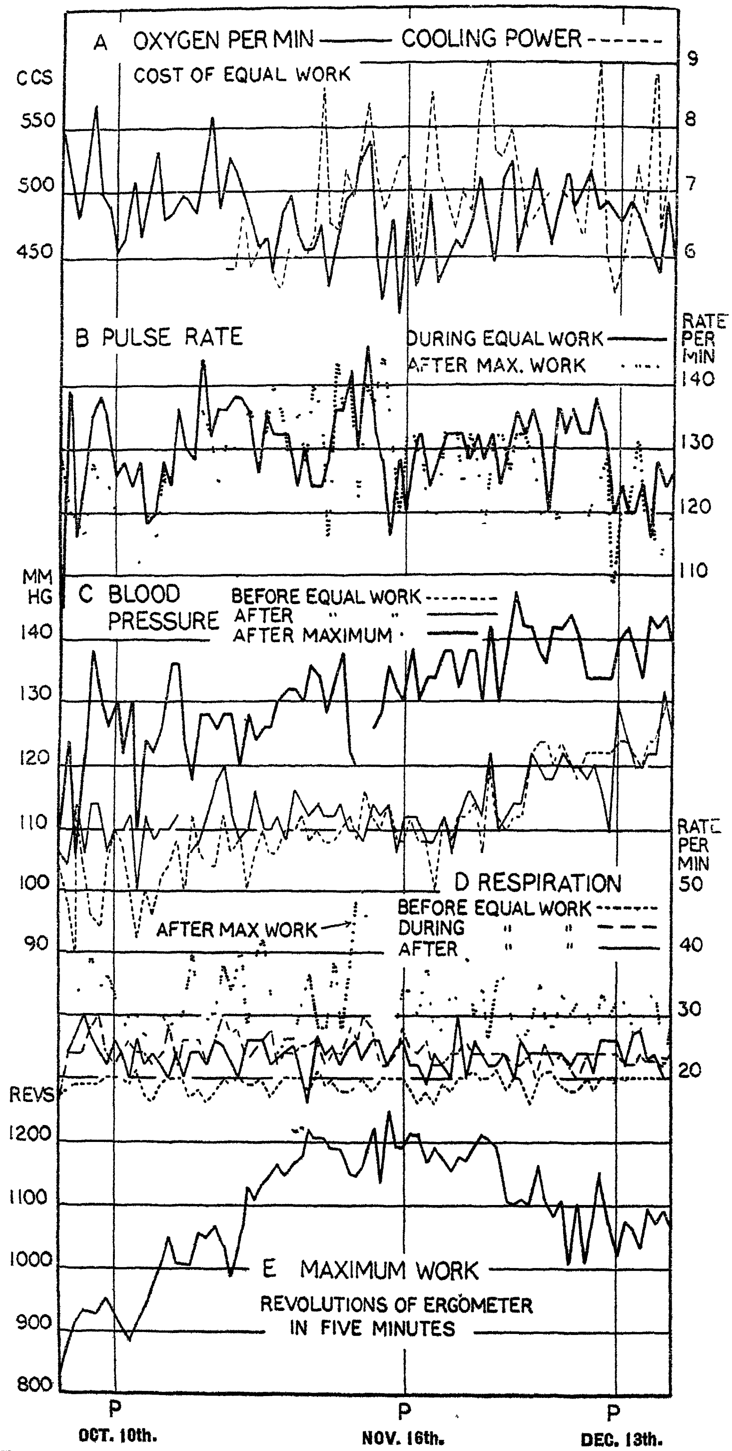

FIG. 3.—A. Metabolism during equal work and simultaneous Kata thermometer readings. B. Pulse rate during equal work and after maximum work. C. Systolic blood-pressure before and after equal work and after maximum work. D. Respiration rate, before, during and after equal work and after maximum work. E. Amount of work performed each day with maximum effort for five minutes. October 2nd to December 19th.

The falls which occur in all three of these curves at menstruation are no greater than many other dips for which no reason can be positively assigned, but their persistence cannot be ignored. The general level of the pre-work pulse (not shown in the figure), like that of the basal pulse, rises in the second half of the experimental period; the curves for work and post-work pulse rates are too irregular for such simple comparison. The relative stability of the working pulse between the second and third menstruation may, perhaps, be connected with specific training, as distinct from general fitness. While in the last weeks there was slight chronic fatigue, improvement of the muscles of the arms and shoulders continued to the end, and this rhythmical work was always found agreeable and in no way taxing, even on days when "tired" or "headache" is specially noted on the record sheets.

The Blood-Pressure during Ergometer Experiment.

The systolic blood pressure was determined, sitting before work, and again between the 35th and 40th second after stopping work (Fig. 3 C). Here there seems to be no fall at menstruation; indeed, there is rather a slight rise about the critical day. But really the curves show no monthly rhythm. They have an interest, however, in showing a steady upward trend, especially marked in the last weeks, where the post-work pressure is, on the whole, lower than the pre-work. That this is not a seasonal variation, but a fatigue symptom, seems the more probable from the fact that when the experiment was repeated in the middle of January, both points were considerably lower, the pre-work pressure being 12 millimetres below the post-work.

The Respiration Rate.

The respirations were counted before the work, during the taking of the sample, and during the first half-minute after stopping (Fig. 3 D).

H. *A Test of Maximal Effort.*

The object of this test was to see whether or no the capacity for extreme short-period effort varies with the menstrual cycle. The subject was required to work the levers of the ergometer, with a load of 1½ kilograms, at the highest possible speed for exactly five minutes. This was a psychological no less than a physiological test, for concentrated attention was demanded to keep up the speed far beyond the normal for continuous muscle work. In the first spurt, lasting generally less than forty seconds, very rapid movement was easily performed, but as general and local fatigue came on, the whole mind had to be given to the question

of speed, and any distraction, such as someone passing through the room, resulted in a loss of pace. There was always a second spurt in the last minute or half-minute. The observer called the minutes, but the subject could form little judgment of her own performance. In the latter weeks she was often persuaded that she was breaking the record when actually the output of work was declining daily.

This experiment followed immediately on that just described, with an interval of two minutes or less for taking pulse and adjusting the ergometer. The fact that the whole organism was already warmed up to work made the task easier.

Fig. 3 E shows the total revolutions in five minutes, Figs. 3 B and D the pulse and respiration rates on ceasing work, while the blood pressure is plotted on Fig. 3 C. All these determinations were made by the same routine method as those in the previous experiment.

The first part of Fig. 3 E recalls a typical practice curve; the second part, with its suggestion of end-spurt, seems to be a typical fatigue curve. The decrease in work performance may be dated from the highest point, November 13th, 1,240 revolutions; or, perhaps, it is more just to regard the curve from November 3rd to November 27th as the high plateau of optimal performance. In either case the curve, for vital capacity (Fig. 1 E) affords a contrast. There the highest point is reached on October 31st, and the decline from it is fairly steady. There is thus objective evidence of declining vigour nearly a month before the same thing definitely appears in the speed test, which was much more under voluntary control. It may be presumed, therefore, that the reduced capacity for output was not due merely to superficial boredom with the routine.

Fig. 3 E shows a break in the rising curve at the first menstruation; the second perhaps coincides with the turn of the curve in general, though there is a good inter-menstrual recovery from November 24th to November 27th; the third menstruation also shows a slight dip. In each case output is also reduced on the day before the onset of the flow. But considering the whole curve as it stands, there is hardly evidence of disability at menstruation, for the decreases are not greater than many others of chance origin.

There did not appear to be any definite correlation between the maximum revolutions and the cooling power of the air.

The curve for blood-pressure, as taken forty seconds after this work (Fig. 3 C), is interesting; it rises steadily to the end, in spite of the diminution of work performed.

Considering the curves for pulse, blood-pressure, and respiration, both in this maximal work and in the easier regular work, it may be seen that there are no such excursions at the menstrual periods as to indicate that the performance of physical work at these times entails an undue strain on the organism as a whole.

COMPOSITE RESULTS.

Moore and Barker (28), in a recent paper (1923) on " Monthly Variations in Muscular Efficiency in Women," used a simple statistical device for reducing the influence of accidental variations and so bringing to light any constant rhythm which might underlie them. The successive cycles were superimposed by arranging the values for the first day, second day, etc., in thirty vertical columns, beginning with the first day of menstruation. The average so obtained gave a curve which was still further smoothed by averaging each value with those of the two adjacent days. In the composite values so obtained, the influence of chance is much reduced, and in the paper referred to, and in that of Moore and Cooper (21), the existence of a cyclical rhythm is demonstrated.

Such a method is well adapted for analysing the data obtained in an extensive study of several subjects and several cycles. It is with diffidence that one applies it to an intensive study of one subject over three cycles only. But the chance fluctuations here must be of lesser order than in the case of uncontrolled subjects, and since examination of the curves *in extenso* has shown evidence of a rather persistent inter-menstrual heightening of values, and of menstrual depression, it seemed possible that the chance variations here, too, would cancel each other out, leaving a fundamental rise and fall obvious.

The method of Moore and Barker has, therefore, been adopted, except that the cycle was 28 days instead of 30, composite values being calculated as described above, and being expressed as variations on an average of 100. In the second cycle, where there are eight extra inter-menstrual days, these values are superimposed on those for the sixteenth to twenty-third days, so that here there is an average of four instead of three in the curves for temperature, basal metabolism, and other basal data detailed in Part I B. In the ergometer experiments, which did not begin until twelve days later than the basal and temperature observations, these extra days are utilised to fill up the gap in one inter-menstrual period. This paucity and uncertainty of inter-menstrual data makes it impossible to attach much significance to the exact *form* of the inter-menstrual rise, which is a feature of all the curves in Figs. 4, 5, and 6.

The validity and usefulness of such a method of averaging seemed especially problematical in two sets of data, viz., the vital capacity, where there is a very marked downward trend, and the maximal effort, where there is a broad rise and fall unconnected with the sexual cycle. However, when these data are treated by the same method as the others the typical monthly rise and fall seem to be demonstrated under the larger trends.

Examination of these average curves shows an undeniable heightening of functional activity, usually in the late inter-menstrual phase, and a depression of about the same magnitude at or shortly before the onset of menstruation.

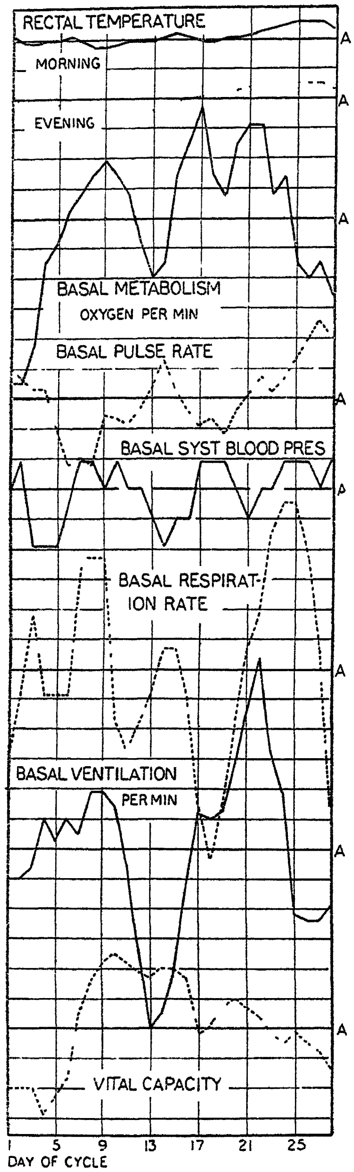

FIG. 4.

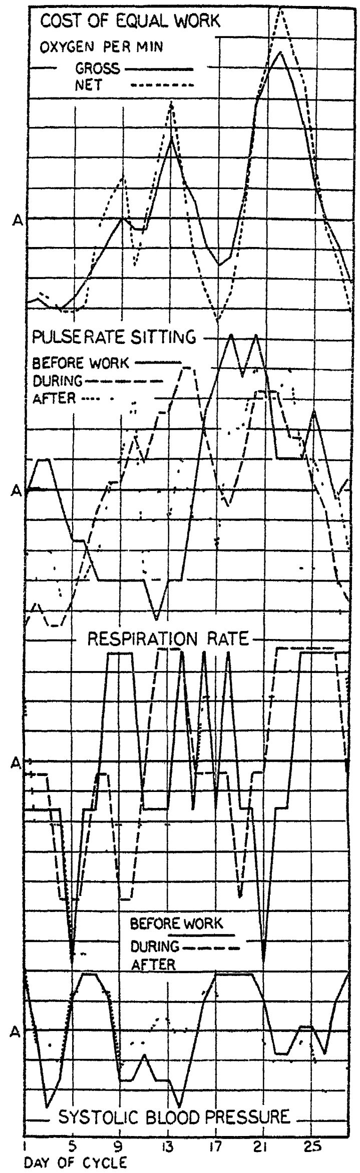

FIG. 5.

FIGS. 4, 5 and 6 show curves of the various observations smoothed by superimposition of three cycles. Each series of observations is reduced to percentages of its average value, shown by a relatively heavy horizontal line. The distance between the horizontal lines is equivalent to one per cent. of the average.

FIG. 4.—Rectal temperature at 7 a m. and midnight, basal pulse rate, respiration rate, ventilation per minute, and vital capacity.

FIG. 5.—Gross and net oxygen consumption per minute during equal work. Pulse rate before, during, and after equal work. Respiration rate before, during and after equal work. Systolic blood-pressure, before and after equal work.

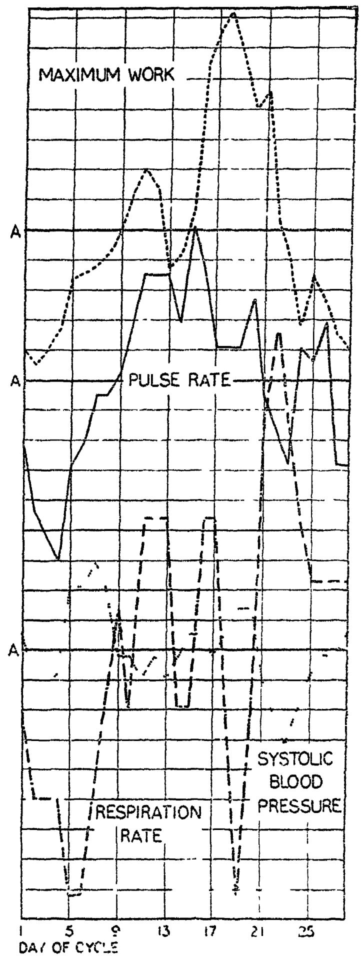

FIG. 6—Maximum work, pulse rate, respiration rate, and systolic blood pressure after maximum work.

SIGNIFICANCE OF THE CYCLE.

No attempt can be made here to discuss the various theories of menstruation and its relations to the development of the ovum and of the corpus luteum. Reference, however, may be made to two interesting discussions on the problem which have recently appeared by Sfameni, 1922 (43), and by Corner, 1923 (44)—the latter including a critical review of experimental work on oestrus, ovulation and menstruation in lower animals. The concensus of evidence seems to be that, in the human female, the mature ovum escapes from the follicle somewhere about the fifteenth day after the onset of menstruation ; that the development of the corpus luteum begins two or three days later ; and that its retrogression

sets in about the time of the next menstruation. Sfameni describes two active and two resting phases, which may be described as follows, the days being numbered from the onset of menstruation :—

1. Activity—maturation of ovum and rupture of follicle (9th to 15th day).
2. Rest (14th to 17th day).
3. Activity—development of corpus luteum (16th to 28th day).
4. Rest—retrogression of corpus luteum; menstrual and post-menstrual phase (1st to 11th day).

According to this, that heightening of functional activity, often accompanied by a subjective sense of vigour, which seems to be characteristic of what I have loosely called the late inter-menstrual phase, would belong to Phase 3, in which the development of the corpus luteum takes place. Sfameni holds that the rupture of the follicle coincides with, and explains, the phenomenon of "middle" pain, which he implies to be of general occurrence. It may be noted, however, that only one of the twelve hundred girls examined by Sanderson (37) experienced any "middle pain." Yet there is some objective evidence of a mid-cycle depression. Thus, Collett and Liljestrand (19) say, "Two maxima (pre- and post-menstrual) and two minima (menstrual and inter-menstrual) are known to occur in body temperature (Jacobi, Vicarelli, Reiul, Zuntz), in blood pressure (Siuday and Francillon) and in muscular strength (Moore and Barker)," and they, C. and L., find two maxima and two minima in basal metabolism also. Three of the writers whom they quote have not been accessible to me, but the rest do not agree very certainly with each other, nor with Sfameni's scheme. For instance, the temperature seems to fall abruptly from about its highest point with the onset of the menses; but the fall in muscular activity was found on the 23rd day, while the maximum for basal metabolism was stated to be from the 15th to the 19th day, which Sfameni regards as a resting phase.

These differences are perhaps no greater than the disagreements as to the date of ovulation (*vide* Corner) but disagreement of various phenomena in one subject, within the cycle, is particularly puzzling. For instance, if the basal metabolism does indeed fluctuate with the sexual cycle, as the new data given in the present paper seem to confirm, it is reasonable to suppose that that fluctuation is causally connected with the temperature rhythm; yet in the data here submitted, the temperature was maintained at its high level until menstruation actually began, while basal metabolism tended to fall from the 25th day,* as did various functions.

* The lowered temperature may of course be regarded as due *in part* to lowered metabolism, and in part to greater heat-loss from the surface.

It must be emphasized, however, that no great stress can be laid on the exact shape of the inter-menstrual curves in the average results here given, because one of the three cycles was unduly prolonged, and therefore has duplicated values for the 15th to 22nd days inclusive. It was impossible to say to which phase these extra days really belonged, but the five days preceding the second menstruation were assumed to be the normal pre-menstrual days. It follows that while the beginnings and ends of the curves are as trustworthy as the averages of three cycles can be, and while the difference between the highest and lowest values is of about the correct magnitude for averages, it is not admissable to locate the point of ovulation with its subsequent two or three depressed days, nor dogmatically to state on which days the (supposed) stimulating influence of the developing corpus luteum is at its height. All that can be claimed for these new data is that they tend to confirm the scanty evidence for a normal heightening of functional activity, including basal metabolism, in the late inter-menstrual phase, followed by a diminution of about the same proportions, which reaches its lowest point during menstruation.

CONCLUSION.

The evidence of the present experiments seems to be that a periodic heightening of functional activity above the average occurs late in the inter-menstrual phase of the monthly cycle, and that a corresponding reduction below the average is found shortly before or at the onset of menstruation. This appears to be the case for temperature, basal metabolism and vital capacity; for muscular tone, as evidenced by the energy expenditure upon measured work; and for physical and psychological capacity for maximally rapid muscular work. The same thing is seen in respiration rates, and in pulse rates and blood-pressure as influenced by work; but the basal pulse rate is rather indefinite, and the basal blood-pressure inconclusive.

The fact that the reactions of respiratory and circulatory mechanisms to muscular exertion, as well as the metabolic costs, are reduced at the period of lowered vitality, seems evidence that no undue strain is laid upon the organism by the performance of physical work at such times. Functional activity, as a whole, seems to be lowered, and, therefore, external work (at least if well within the subject's normal capacity) is performed at a lower physiological cost. This incidentally affords a warning against the fallacy of pressing, indiscriminately, the analogies of mechanical efficiency to the workings of the human body. No one would maintain that such a lower level of functional activity is more beneficial to the body than its average level, and most people would consider that the days when mechanical efficiency on fixed work is lowest, because functional activity is at its height, are the optimal days from the point of view of the body's health.

The magnitudes of both the stimulation and depression of function are of small order, about 5 per cent. in each case; and accidental depressions as great as that which recurs with menstruation are of frequent occurrence. *Therefore, there seems no reason to think that the fundamental physiological rhythm in women is such as to affect, either considerably or constantly the quantity or quality of their industrial work, provided always that no pathological conditions are present.* Evidence of periodic variation of this order is of some scientific interest, but of little practical importance, because it is within the range of accidental fluctuations. It seems, moreover, that variations, almost or quite as great, and as frequent, occur normally in the physiological processes of men also, though no regular rhythm has been demonstrated, and there is but little evidence of a sexual cycle in the male.

With regard to the broader trends and changes of level in functional activity which came to light over the whole three months' experiment, no interpretation can be put forward without further investigation. There were here at least three factors at work: the change of season; a progressive general fatigue; and an improvement of the musculature of the subject's arms and shoulders, probably accompanied by such general "training" as cardio-vascular adaptation, etc. Judging by the data, the woman's appearance and her subjective estimates, one would say that the second of these factors was the most important. The following points may be enumerated without further comment. The basal metabolism, basal pulse rate and blood-pressure rose during the last weeks. The vital capacity fell from the end of October, and during December maintained a level about 500 cc. less than the best values for October; in early January it had recovered about 400 cc. The blood-pressure, sitting still before work, rose steadily over the last weeks, and was often higher than the blood-pressure as determined 40 seconds after work ceased, which, however, was also trending upwards; the normal levels and normal difference between pre- and post-work pressure were observed again in January. The performance of maximally rapid work on the ergometer improved through October, was fairly maintained through November, in spite of a decrease during the menstrual days, and fell considerably from the last days of November though there was a slight recovery in the third week of December. The blood-pressure, 40 seconds after this work ceased, grew steadily higher to the end of the experiment.

It is a pleasure to express my thanks to Professor E. P. Cathcart, F.R.S., for supervising this research, which was conducted at the Physiological Institute, Glasgow University, and to Dr. G. M. Wishart for his very great care and patience in assisting at the daily experiments.

SUMMARY.

1. Observations were made on a woman under controlled conditions of diet, exercise and sleep, for ninety-two consecutive days.

The data collected consist of temperature, basal metabolism, vital capacity, energy expenditure on fixed work, and a maximal effort test, together with determinations of pulse, blood-pressure and respiration rate in various circumstances.

2. The data on the whole indicate a heightening of the functional activity in the later inter-menstrual period, and a fall at menstruation.
3. The depression of function which recurs at menstruation is of no greater magnitude than frequently occurs accidentally.
4. There is no evidence that this particular healthy woman was rendered physiologically ineffective during menstruation.
5. As an unforeseen by-product, the data yield some indications of physiological symptoms of a general slight progressive fatigue.

APPENDIX.

REVIEW OF PREVIOUS WORK.

Reviews of the literature on functional periodicity in women are available in Zuntz (1) (1906), King (2) (1914), and Hollingworth (3) (1914), and include references to work (up to those dates), on several aspects of the subject not considered in the present investigation. The references here given are chiefly to papers concerned with the particular physiological phenomena for which some further data are to be put forward.

Temperature.

Periodicity in temperature is well established. There is a rise of temperature of about one degree, culminating a day or two before, and an abrupt fall coincident with the onset of the menses. Rabuteau (4) observed it in 1870, and it has been confirmed by Jacobi (5), Stephenson (6), Van Ott (7), Giles (8), Vicarelli (9), Mandl and Bürger (10) Zuntz (1), King (2), Cullis (11).

Basal Metabolism.

A reduced production of CO_2 by menstruating women was stated by Abdral and Gavarnet (1843) to be demonstrable (cit. Jacobi (5), p. 103). Sfameni (12), writing in 1899, quoted Cuzzi (13) as finding the same thing. The first reliable work by modern methods, and still the best, is that of Zuntz (1) (1906), who obtained data on 97 days from two subjects. He stated that his results showed no indication of rhythmic rise and fall, and he attributed the lower temperature during menstruation to surface baso-dilation and increased sweating.

Gephart and Du Bois (14) gave data for a woman on the second day of the catamenia, and again for the third day after the flow had ceased. Their figures show that the metabolism, as measured by indirect calorimetry was very slightly lower on the first occasion, and the heat elimination perceptibly higher. The authors were not specifically interested in the menstruation factor and made no comment.

Snell, Ford and Rowntree (15), in a preliminary report, stated that two of their ten subjects showed a fall of metabolism during menstruation, and that the other eight had a fairly constant rise during or just before the onset, and a post-menstrual fall. They gave no figures.

Blunt and Dye (16) gave observations on fourteen women over one or more cycles, and concluded that there is no periodic variation.

Wakeham (17) found "a distinct fall in basal metabolism during or immediately after menstruation," and his analysis of Blunt and Dye's data reveals the same tendency there also.

Wiltshire (18) found no correlation of the sexual cycle with basal metabolism, nor with cost of work or rate of recovery.

Collett and Liljestrand (19) found maximal points at four to ten days, and again at fifteen to nineteen days, after the onset of the menses, and minimal points on the first or second day of the flow, and again ten to eighteen days later.

Rowe and Eakin (20) found individual rhythms in both male and female subjects, not dissimilar in the two sexes, but more marked in the female, where the curve is highest in the week preceding menstruation.

Respiration Rate, Pulse Rate, Blood Pressure.

For respiration and pulse rate determinations have been made by Jacobi (5), Van Ott (7), Mandl and Bürger (10), Zuntz (1), Moore and Cooper (21), Cullis (11), Collett and Liljestrand (19). While there is a certain amount of doubt and conflicting opinion, the general trend of the evidence seems to be that, in the absence of pain and of external disturbance, a lower pulse rate is observed during menstruation, while in the inter or pre-menstrual phase there is a rise clearly above the average. The respiration rate tends to conform to the pulse curve, and Collett and Liljestrand (19) found the same in the minute-volume.

For Blood-Pressure, Jacobi (5) found a minimal phase one to four days after the cessation of the menses, and a maximum seven to eight days before the next period. *Stephenson* (6) found the maximum six or seven days before, and a fall beginning one or two days before, the onset of the menses. *Giles* (8) on the other hand, found the blood-pressure highest on the first two days of menstruation, and on the day preceding it. *Mosher* (22) found a fall occurring at or near menstruation, followed by a rise distinctly over the normal line, but she found similar variations in the curves of her male controls. *Wiessner* (24) found a pre-menstrual rise and a menstrual fall, and so also did *Mandl and Burger* (10). These latter authors also added that in cases where the uterus had been removed they found the variation persistent; but in cases where the ovaries had been removed also, there was no indication of the wave-form in pressure. *Bogdanovies* (25) found a pre-menstrual rise and a gradual fall from the onset of the catamenia. *King* (2) found that ten of her eleven subjects showed such irregular variation of blood pressure as to give no support to the wave theory. Recently *Cullis* (11) published some figures of an indecisive character, and *Amos* (26) some observations which, unfortunately, were not taken in the resting condition *Moore and Cooper* (21) in eight subjects over two to seven cycles, found evidence of rhythm in systolic, diastolic, and pulse pressure, circulatory index, pulse rate and respiration rate.

Reference may here be made to two studies of kindred interest Van Ott (7) found increased heat loss during menstruation, and Sfameni (12), in the peripheral blood, found decrease of haemoglobin and of the red corpuscles at menstruation, and increase of leucocytes just before and during the flow.

Mental and Motor Efficiency.

Periodic variations in muscular strength have been studied by Jacobi (5), Van Ott (7), Bossi (27), Mandl and Bürger (10), Moore and Barker (28).

While all found some evidence of menstrual depression, *Jacobi* (5), and Moore and Barker (28) concluded that there is nothing to indicate that normal menstruation should interfere with ordinary activity.

King (29) also thought that her data showed that the inefficiency of women during menstruation has been over-emphasized. In observations on the knee-jerk, King found a period of hyper-excitability immediately preceding, during, or immediately following the menses, with a subsequent fall, and then a return to normal.

Van Ott (7), also by means of the knee-jerk, claimed to have detected hyper-activity of the nervous system during the haemorrhage.

Collett aud Liljestrand (19) stress rather vague pre-menstrual symptoms and "nervousness"; but it is not established that such symptoms and nervousness are generally experienced by normal girls and women. Somewhat after the same pattern are innumerable general impressions founded on no exact data, such as are quoted by Hollingworth (3) in her "Functional Periodicity." In this monograph is presented a quantity of data of an objective psychological nature, on men as well as women. The author concluded that the curves representing tests on males and females show variations indistinguishable in character, and that there is no foundation for supposing that normal menstruation is accompanied by functional depression.

Voisechovsky (30), as cited by Hollingworth, found, on the other hand, that "menstruation has an unquestionable influence on women's psychic sphere which may be stated in the objectively psychological way." Hollingworth raised the objection that he had no male controls, and thatsthe subjects were not "naive" to the purpose of the experiment so that elf-conscious agitation on the critical days may have affected their psychological reactions.

Industrial and School Observations

The importance of this question of periodic depression, if it is as marked a phenomenon as some writers maintain, should have given rise to more

scientific investigation, from the point of view of industrial efficiency, than apparently it has. Only the most fragmentary evidence seems to be available on the relation of menstrual health to working capacity, fatigue, accidents, or lost time All books on Scientific Management refer to a spectacular success of the new methods in the case of girls testing bicycle ball bearings. One of the changes introduced was that every girl was given two consecutive days of rest, with pay, every month (31).

Lee (32) quotes statistics showing that women between the ages of twenty and fifty lose many more working days through sickness than do men between the same ages, and he implies that this is due as much to menstrual disability as to child-birth. He also refers to an investigation by Epstean, apparently unpublished, where ten healthy young women showed, over five months, an average diminution in " total muscular strength " of 5 per cent. during the menstrual days.

The heavier incidence of sickness on women than on men is shown in the " Report of the Departmental Committee on Sickness Benefit Claims under the National Insurance Act, 1914 " (33), and is quoted and discussed in the " Report of War Cabinet Committee on Women in Industry, 1919 " (34). In the " Final Report of the Health of Munition Workers' Committee " (35) it is stated that 26 per cent of the women employed in the factories investigated suffered " disorders of menstruation " of various degree.

Recently Sturgis (36) has published a paper on " Dysmenorrhea in Women employed in a large Departmental Store." This study was based on physical examinations of 2,077 women employees, between the ages of sixteen and sixty. " Each employee was carefully questioned as to discomfort, pain, loss of time necessitated by her menstrual period." It was found that 65 per cent. had no menstrual handicap ; 30·6 per cent. had only a slight handicap ; and only 4·4 per cent. were seriously handicapped.

Sanderson (37) has published a paper on " Menstruation during School Life." As a result of the examination of 1,200 girls she found that 73 per cent. suffered no pain or discomfort. Subsequently, 734 of these girls were examined a second time. At the first enquiry 67 per cent. of them had declared that they suffered in no way ; at the second this proportion had risen to 85 per cent. Dr. Sanderson recommended exercise and hot baths during menstruation, and attributed the improvement at the second examination to their use by girls who had previously avoided them.

The *British Medical Journal* (September 27th, 1924) published a most interesting discussion of the Section of Obstetrics and Gynaechology at the B.M A. Annual Meeting, Bradford, 1924. The subject was *Dysmenorrhea in Young Women ; Its Incidence, Prevention and Treatment*, and the discussion was opened by Dr. Sanderson Clow (cp. Ref. 37). The consensus of opinion was that dysmenorrhea is less common than is supposed, and can generally be cured by exercise, hot baths, and a sane mental attitude towards this natural function.

Some statistics of the menstrual health of American school-girls, students and graduates are referred to by Hollingworth (3).

In weighing the evidence for and against periodic fluctuation in the functional activity of the female organism, it must be borne in mind that the experimental findings summarised above are of very unequal value. In a few cases, e.g. Van Ott (7), neither the original figures nor graphs drawn from them seem to have been published. Difficulties of technique, especially in the earlier work, and difficulties always in controlling irrelevant physiological and mental conditions, make perfectly reliable records exceedingly hard to procure. Extensive studies of many subjects have a great advantage in the cancelling out of chance variations, and personal peculiarities ; on the other hand, accurately controlled conditions can only be hoped for when the subjects used are few and well-trained. The literature referred to above includes both classes of study.

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A Physiological Investigation of the Radiant Heating in Various Buildings.

By H. M. Vernon, M.D., and M. D. Vernon, M.A.,
assisted by Isabel Lorrain-Smith, M.A

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PREFACE.

The artificial heating of factories has already been the subject of investigation under the Industrial Fatigue Research Board, and in 1926 a report was published by them consisting of a physiological study of certain types of ventilating and heating systems in actual use and of a comparison of their principal characteristics ([1]). This work has since been continued to cover certain forms of radiant heating, and particularly panel heating, a method that is now being widely adopted in buildings.

The results of this second investigation, which are embodied in the present report, suggest that the chief advantage of radiant heating is the remarkable uniformity of temperature throughout the room and the consequent absence of the steep vertical temperature gradient that often accompanies heating by convection. On the other hand, little confirmation could be found of the claims sometimes made for radiant heating, namely that it differs from other systems in possessing certain inherent qualities productive of comfort, and in ensuring comfortable conditions at a much lower air temperature.

The Board desire to acknowledge their indebtedness to the managements of the different establishments visited for the facilities for investigation accorded by them.

December, 1927.

([1]) Vernon, H M. and Bedford, T., assisted by Warner, C. G. (1926).— —A Physiological Study of the Ventilation and Heating in Certain Factories.—*Ind Fat. Res Board, Report No* 35.

P.2703 M&S. 7562^4 572 500 7 29.

A PHYSIOLOGICAL INVESTIGATION OF THE RADIANT HEATING IN VARIOUS BUILDINGS.

By H. M. Vernon, M.D. and M.D. Vernon, M.A., Investigators to the Board, assisted by Isabel Lorrain-Smith, M.A.

CONTENTS.

PART I. THE MEASUREMENT OF RADIANT HEAT.

By H. M. Vernon, M.D.

Introduction.

It is widely believed that radiant heat, such as is yielded by coal fires and gas fires, is more pleasant and exhilarating to the human organism than heat from hot-water pipes and radiators, because the latter sources of heat chiefly transmit by convection currents of hot air and only to a minor degree by radiation (*cf.* Barker, 1923). Plenum air heating yields a still smaller fraction of radiant heat, and partly on that account is even less in favour. Gas and coal fires are not suitable for large buildings, however, and in recent years a novel form of radiant heating known as *panel heating* has been coming into favour. This usually consists of concealed coils of pipes, through which hot water flows, running in the ceiling or walls of the room, or under the floor. Large surfaces are thereby maintained at a moderate temperature, and they radiate heat in all directions.

In order to investigate the panel heating installations in various buildings, it was necessary to have some portable apparatus for measuring it. This took the form of a Moll thermopile, connected with a Cambridge and Paul unipivot dead-beat galvanometer of 7·7 ohms. resistance. The thermopile contained 80 junctions of constantan and manganin of extreme thinness, the strips of metal being supported at each end on flattened copper pins. These pins are fixed in a brass plate in parallel rows (though separated from metallic contact with it by a layer of lacquer), and form part of the passive junctions of the thermopile. Both active and passive junctions are exposed to the radiant heat, but owing to the small heat capacity of the strips, and the large heat capacity of the pins and the brass plate, the thermopile is not only extremely rapid in its response, but it is comparatively little affected by variations in the temperature of the air and by exposure to continuous radiation(1).

The Calibration of the Thermopile.

In order to calibrate the thermopile and galvanometer, two radiant test surfaces were employed. One consisted of a small tin, with a matt black surface, which contained 14 ounces of water. Its temperature was kept to within about 2° F. of the air temperature of the room, and in the observations to be described subsequently the thermopile was always placed with its cone facing the tin and within ¼ in. of it, before and after any measurement of the heat radiating from a surface to which the thermopile had been turned. Readings were not attempted

(1) For a detailed description of the instrument *cf.* W. J. H. Moll (1923)

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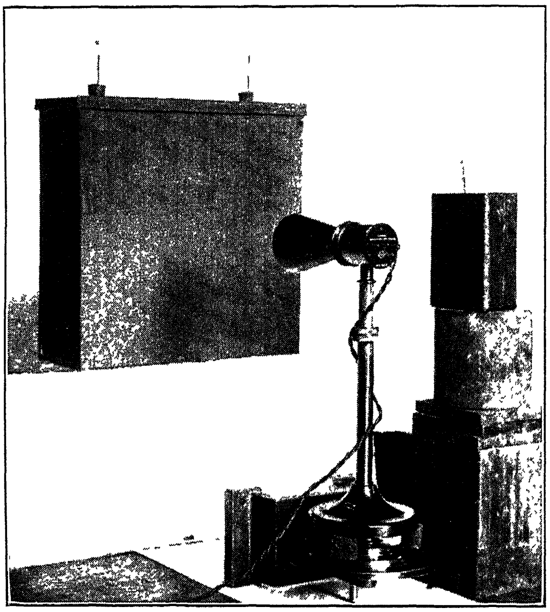

FIG 1 Thermopile, and standard surfaces used in calibration

until the galvanometer connected with the thermopile showed a deviation of not more than one scale division from zero. This sometimes necessitated a wait of half an hour at the beginning of the day's work, when the thermopile was first set up.

The other test surface consisted of a copper vessel 12 in. square and 4 in. deep. It was brightly polished everywhere except on one side, which was painted over with a single thick layer of lamp black in aqueous suspension. The vessel was filled to the brim with water at various temperatures, and was kept at a steady temperature during the observations by a small gas flame. Any radiant heat from the flame was prevented from reaching the thermopile by a sheet of asbestos, as is shown in Fig. 1, whilst a larger sheet of asbestos was interposed between the thermopile and the copper vessel except during the short times of exposure to its radiation. The thermopile was supported on

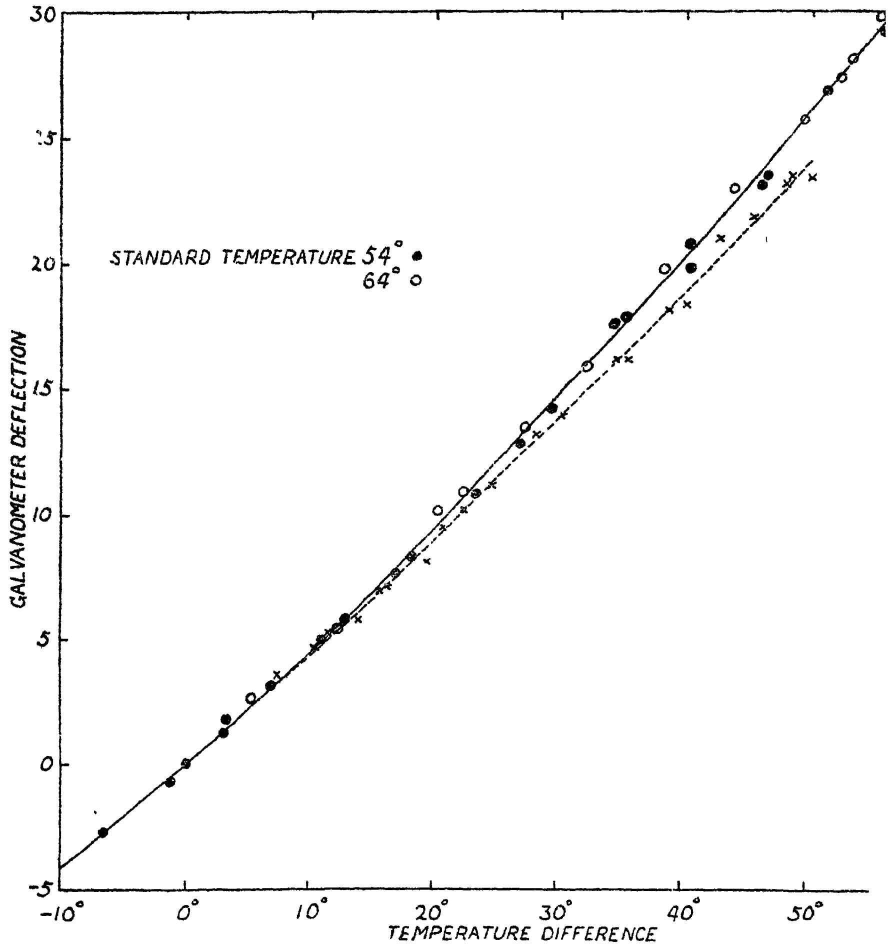

Fig. 2. The relationship between temperature difference and galvanometer deflection

a turntable, and could be turned from one standard surface to the other in a fraction of a second. The galvanometer deflection reached a steady value in less than 10 seconds, as is demonstrated below (*cf.* Fig. 4). When using the thermopile, the protecting glass disc was removed, because it entirely stopped the penetration of the heat rays to the junctions. The disc of rock crystal supplied with the instrument was not used, for though it transmits most of the heat rays, it is inconvenient for general use owing to its extremely hygroscopic nature.

The chief series of observations are plotted out in Fig. 2, ordinates representing galvanometer deflections, and abscissae, the difference between the temperatures of the water in the two standard vessels (in °F.). The dots relate to observations made when the temperature of the water in the small tin was at 54° F., whilst the circles relate to similar observations made when the temperature was at 64° F. It will be seen that, on an average, these circles are slightly above the mean curve, whilst the dots are slightly below it (as would be expected from the fourth power law, referred to below). So the mean curve itself may be taken to show the relationship between galvanometer deflection and difference of water temperature, when the standard temperature was at 59° F., or 15° C. In making these observations the thermopile was so placed that its cone came within ½ in. of the lamp-blacked surface of the copper vessel, the manganin-constantan junctions then being 4¼ in. from it. Another series of observations was made (at a standard temperature of 61° F.) in which the junctions were 12 in. from the centre of the lamp-blacked surface, whilst the cone of the thermopile was 8 in. from it. As can be seen from the crosses in Fig. 2 and the dotted line drawn through them, the galvanometer deviations were distinctly smaller than in the other series. Hence it follows that a small amount of radiation entered the cone from the cooler areas outside the square foot of lamp-blacked surface.

In about half of the observations recorded the temperature of the copper vessel was gradually raised, and in the other half, gradually lowered, the results agreeing very well. In a few observations the temperature of the water in the copper vessel was lower than that of the air, and a negative galvanometer deflection was observed. It will be seen that the curves in Fig. 2 are not linear, but show a gradual increase of galvanometer deflection for equal increments of temperature. In Table I are recorded the deflections corresponding to temperature intervals of 9° F., or 5° C., and it will be seen that they range between the extremes of 3·8 and 5·3. They are approximately in accordance with the "fourth power law," which was calculated by Stephan from experimental data obtained by Tyndall. According to this law, the rate of loss of heat by radiation varies as the fourth power of the absolute temperature, and the correctness of the law has since been confirmed by Lummer and Pringsheim for temperatures ranging from −190° to 2300° C. The radiation R from a body of

TABLE I.—*Relationship of thermopile effect to expected radiation calculated on the fourth power law.*

Temperature.	Galvanometer Deflection	Calculated increase of Radiation.	Ratio of Galvanometer Deflection to Radiation Increase
10°–15° C (50°–59° F) ..	3·8	4·66	0·82
15°–20° C. (59°–68° F.) ..	4·0	4·90	0·82
20°–25° C (68°–77° F) ..	4·4	5·16	0·85
25°–30° C (77°–86° F) ..	4·7	5·43	0·87
30°–35° C. (86°–95° F) ..	4·95	5·70	0·87
35°–40° C (95°–104° F) ..	5·15	5·99	0·86
40°–45° C (104°–113° F) ..	5·3	6·28	0·84

emissive power E and with a surface S at a temperature θ in an enclosure at a temperature θ_o is given by the formula :—

$$R = E\ S\ (\theta^4 - \theta_o^4)$$

where σ is the radiation constant(1).

Applying this law to the data in Table I, the increments of radiation produced by each rise of 5° C. in temperature are recorded in the third column of the Table. In order to reduce them to a convenient measure they have been divided by 10^8, and in the fourth column of the Table are recorded the quotients of galvanometer deflection/radiation. It will be seen that they are nearly constant. Hence it follows that the data obtained conform to the fourth power law, and at the same time they indicate that the galvanometer deflections were in direct proportion to the E.M.F. of the current derived from the thermopile at various temperature differences.

In order to obtain further information about the size of the radiant area measured by the thermopile, observations were made with the thermopile at various distances from the centre of the copper vessel, and at right angles to it. In the results recorded in Fig. 3 the temperature of the standard tin of water was 61·0° F., and of the copper vessel, 106·7°, or 45·7° higher. It will be seen that as the distance of the thermopile junctions from the radiant surface increased from 4¼ to 12 in. there was a slight fall in the galvanometer deflection, whilst at further distances there was a rapid and steady fall. At distances of 1, 2 and 3 ft. the deflection was 21·9, 14·0 and 7·0 respectively. These figures appear to indicate that the thermopile cone subtends a circle of 8·5 in. diameter when 1 ft. from the radiant source, and therefore a circle of 17·0 in. when 2 ft. away. Thus a 17 in. circle has an area of 227 sq. in., whilst the radiant surface itself had an area of 144 sq. in. Hence the galvanometer deflection of 21·9 observed

(1) *cf.* Encyclopædia Britannica (1911). 13. p. 155.

at 1 ft. distance should have fallen to $21{\cdot}9\times\frac{144}{227}=13{\cdot}9$ at 2 ft. (as compared with the observed value of 14·0), and to 6·2 at 3 ft. (as compared with the observed value of 7·0). However, the fact that the thermopile showed a slightly increased deflection when placed $4\frac{1}{4}$ in. from the radiant surface instead of 12 in. shows that in the latter position a small amount of radiation was collected by the cone from areas lying outside the radiant surface. This radiation is reflected on to the junctions by the polished walls of the metal cone, and such reflection makes an enormous difference to the response of the instrument when placed at a distance from the radiant surface. The lower curve in Fig. 3 indicates the galvanometer deflections observed when the thermopile was used without its cone. With the junctions 6 in. away from the radiant surface the deflection was 22·1 as compared

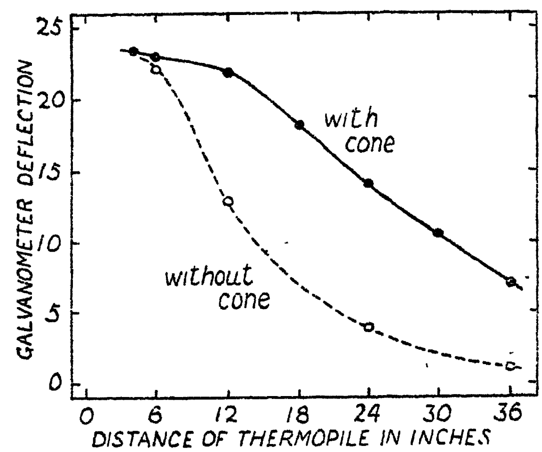

FIG. 3. The effect of varying the distance of the thermopile from the radiant surface.

with one of 22·9 when the cone was in position, but when they were 36 in. away, the deflection was only 1·1 as compared with one of 7·0.

For practical purposes we may assume that when the thermopile, with the cone in position, is turned to a ceiling, wall, or other radiant source, it collects heat from a circle with a diameter equal to three-fourths the distance of the thermopile from the source; e.g., when 8 ft. from the source it collects heat from a circle of 6 ft. diameter.

The remarkable steadiness in the response of the thermopile when exposed to a radiant source was proved by keeping the thermopile for $1\frac{1}{2}$ hours at a distance of 1 ft. from the copper vessel, which was at a temperature of 50° F. above the standard temperature (54° F.). Every 10 minutes the instrument was

turned to the standard tin for a few seconds, and the galvanometer deflection read. The following differences were observed :—

Time of Exposure.	Galvanometer Deflection	Time of Exposure	Galvanometer Deflection.
0·2 min.	23·3	50 min	23·5
10·0 ,,	23·3	60 ,,	23·2
20·0 ,,	23·3	70 ,,	23·3
30·0 ,,	23·4	80 ,,	23·4
40·0 ,,	23·4	90 ,,	23·5

For the next 30 minutes the thermopile was kept facing the standard tin, and at 5 minute intervals it was turned to the radiant surface. Though one side of the body of the thermopile was exposed to the radiant source, this had no effect upon the response.

Time of Exposure.	Galvanometer Deflection.
0·2 min	23·5
5 0 ,,	23·6
10·0 ,,	23·6
15·0 ,,	23·3
25·0 ,,	23·2
30·0 ,,	23·5

In order to test the quickness in the response of the thermopile it was quickly switched backwards and forwards from one vessel to the other at 20 second intervals. The galvanometer was read by another investigator at $2\frac{1}{2}$ second intervals synchronous with the ticks of a metronome, and it will be seen from Fig. 4 that it reached equilibrium about 7 seconds after each change of position.

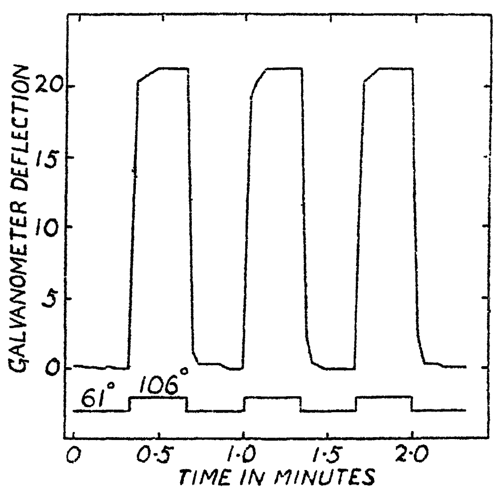

Fig. 4. The galvanometer deflection caused by turning the thermopile from one standard surface to the other.

Radiation from Various Surfaces.

As was previously pointed out, the rate of heat loss by radiation depends, not only on the temperature of the radiant surface, but also on its *emissivity*. The emissivity of various surfaces was first studied by John Leslie (1804), with a cube filled with boiling water. He found that if the radiant effect of lamp-black was taken as 100, that of white paper was 98, of glass, 90, and of bright polished metal, only 12. L. Hill (1920) found the emissivity of glass, gelatin, water, and of the skin surface of human beings to be about the same, whilst Griffiths and Davis (1922) found that the emissivity of surfaces painted with black, dark green, or white paint or enamel was the same as that of a "dead black" surface. A surface painted with aluminium paint (which is much used for hot water pipes and radiators) had an emissivity only 70 per cent. as great.

It is now customary to calculate emissivity in relation to the emission of an absolute black body. Taking this value as 100, that of a lamp-black surface is stated (Hütte, *cf.* Barker) to be 93. Lime mortar has a slightly smaller emission, whilst slightly polished copper has only a sixth as much.

Since the observations to be described in Part II of this Report relate mostly to white-washed and painted surfaces, it was thought worth while to determine their emission by means of the thermopile. On the back of the polished copper vessel used in the calibrations were painted 4-in. circles of cream-white paint (two coats), aluminium paint (three coats) and white-wash (three coats). The thermopile cone was placed within ¼ in. of each of these surfaces in turn, when the copper vessel was 50° F. warmer than the standard tin. Taking the radiant effect of the lamp-blacked surface as 93, the following emissivities were observed :—

Radiating Surface.	Present Observations.	Previous Observations.
Absolute black body ..	—	100
Smooth lamp-black	93	93
Cream paint	91	—
White-wash	91	—
Rough white lime mortar ..	—	90
Aluminium paint	71	—
Slightly polished copper ..	—	17
Brightly polished copper ..	11	—

It will be seen that, in confirmation of previous results, the emission of painted and of white-washed surfaces was found to be about the same as that of lamp-black, though that of aluminium paint was considerably less. This approximate equality of emissivity is a great convenience, for it means that almost all the radiation temperatures recorded in Part II of this Report are

directly comparable to the radiation from a lamp-blacked surface, and that the relationships between radiation and temperature plotted in Fig. 2 hold also for the chief radiating surfaces met with in buildings.

Direct Temperature Observations on Radiant Surfaces.

In order to supplement the determinations of radiant temperature by means of the thermopile, the actual surface temperature was frequently observed by means of thermometers. The thermometer was fixed to the surface with plasticene, care being taken to see that the thermometer bulb was in close contact with the surface, whilst the surrounding plasticene also made good contact. The thermometer was read after 20 to 30 minutes, but it was necessary to apply a substantial correction to its reading because of the loss of heat by radiation from the surface of the plasticene. These corrections were ascertained by fixing a thermometer with plasticene to the copper vessel used in the thermopile calibrations. As the result of a large number of observations, the corrections recorded in Table II were determined.

TABLE II.—*Corrections to temperatures determined by the plasticene method.*

Observed difference in ° F	Per cent Correction	Observed difference in ° F.	Per cent. Correction.
5·0	1·4	30·0	12·8
10·0	3·7	35·0	15·0
15·0	5·9	40·0	17·3
20·0	8·2	45·0	19 6
25·0	10·5	50·0	21·8

They represent the percentage correction to be added to the observed *difference* between thermometer temperature and air temperature. It will be seen that the correction rapidly increases with rise of temperature. It is only 3·7 per cent. for a difference of 10° F., so an observed temperature of 70° (with air temperature of 60°) would be corrected only to 70·4°. For a difference of 50° F. it is 21·8 per cent., so an observed temperature of 110° (with air temperature of 60°) would be corrected to 120·9°.

Observations recorded in Part II of this Report show that there was a fair agreement between the corrected plasticene temperature and the radiation temperature as ascertained by the thermopile, though on the whole the plasticene temperatures were rather too low. This would be expected, because the radiant surfaces investigated were not such good conductors of heat as the copper of the copper vessel used in the calibrations. Hence the corrections given in Table II are minimum values.

The Action of Radiant Heat on Thermometers and Kata-Thermometers.

The radiant heat of the sun is sometimes measured by means of a solar radiation thermometer, the bulb of which is blackened and surrounded by a glass globe from which the air has been evacuated. Such a thermometer is useless for measuring low temperature heat radiation, because the low temperature rays do not penetrate the outer globe of glass. If two thermometers, one with the bulb blackened, are exposed to the same radiant heat source at a low temperature (e.g. 110° F.) the black-bulb thermometer shows a higher temperature than the other, as some of the extra heat absorbed is conducted through the glass; but the difference depends on a number of factors, and especially on the velocity of the air currents impinging on the bulbs. If the two bulbs are fanned vigorously they register practically the same temperature, and the interposition of a screen of polished metal, to prevent all access of radiant heat, makes no difference, because the air currents overpower the small radiation effect.

The kata-thermometer appeared to be a more promising instrument for the measurement of radiant heat, for such heat acts differentially on the dry kata and on the wet kata. I found, for instance (1925), that when such katas are exposed to the radiant heat from large sheets of red-hot steel such as are rolled out by tin-plate mill-men, the wet kata cooling power of the air may still be high (e.g. 18·5), whilst the dry kata cooling power is negative (e.g. —3·7). That is to say, the dry kata is warmed by the radiant heat from 95° to 100° F., instead of cooling down in the usual way. The low temperature radiation which was chiefly the subject of the present investigation could not be expected to produce such a marked differential effect as this, but the observations to be described show that it does produce a measurable difference in the relative rate of cooling of the two katas.

In these observations the kata was placed 6 in. or 1 ft. from the middle of the lamp-blacked copper vessel, the temperature of which was 50° F. above the air temperature. The kata was alternately exposed to the radiant heat, or protected from it by means of a sheet of asbestos, and from the mean results recorded in Table III it will be seen that, whilst the wet kata cooling power was unaltered, the dry kata cooling power was reduced from 6·11 to 5·90 when 6 in. from the radiant source, and to a smaller extent when 12 in. from it. In consequence, the ratio of dry kata to wet kata fell, on an average, from 36 per cent. to 35 per cent.

In nearly all the observations described in Part II of this Report the ratio of dry to wet kata cooling power was determined, and these ratios show that the dry kata cooling power was very slightly affected by low temperature radiant heat, whilst the wet kata cooling power was little if at all affected. However, the difference was so small that it was apt to be hidden by the

TABLE III.—*Effect of radiant heat on kata cooling power.*

Distance of kata from radiant source.	Air Temperature.		Cooling power when exposed to radiant heat.			Cooling power when protected from radiant heat.		
	d.b.	w.b.	Dry kata.	Wet kata.	% ratio.	Dry kata.	Wet kata.	% ratio.
6 inches	59·2°	54·0°	5·90 } 6·11	17·3 } 17·3	34 } 35	6·11 } 6·27	17·5 } 17·3	35 } 36
12 inches	57·3°	52·3°	6·32	17·4	36	6·43	17·2	37

operation of other variable factors such as the velocity of the air currents, the humidity of the air, and the (dry bulb) air temperature. Hence the results recorded are of but slight practical value until more is known of the effects of various factors on the dry kata/wet kata ratio.

When making the above observations, the air temperature was taken by fixing the thermometer within a few inches of the kata, but protecting it from the radiant heat of the copper vessel by a sheet of asbestos. Subsequently, a series of observations was made in which the thermometer was placed 6 in. from the middle of the copper vessel, and was alternately protected from, and exposed to, the radiant heat. On an average, it recorded a temperature of 64·2° when exposed, and 62·3° when protected, or 1·9° less. When the exposed thermometer was fanned vigorously, its temperature fell to the same level as when it was protected but not fanned. When these observations were repeated with a thermometer fixed in a boxwood frame, the temperature of the exposed thermometer was found to be 2·7° higher than when it was unexposed, instead of 1·9°. Presumably this was because radiant heat was absorbed by the boxwood and radiated on to the thermometer bulb. Hence it is evident, as has been pointed out above, that the measurement of radiant heat by ordinary thermometers depends so much on other factors besides direct radiation as to be of very little value.

It has been shown by Leonard Hill (1920) that radiant heat can be measured by exposing a piece of black fur to the radiation, and taking its temperature. It usually indicates a higher temperature than a black bulb thermometer similarly exposed, and in sunlight its temperature may rise 30° to 40° C. above that of the air. Its readings are difficult to standardise, so we did not try it with low temperature radiation.

Summary.

For estimating the heat radiated by ceilings, walls and other surfaces in buildings, a Moll thermopile connected with a unipivot galvanometer was used. The thermopile was calibrated against the radiation of a lamp-blacked copper vessel 1 ft. square. This was filled with water at a temperature varying from 7° F. below that of the standard to 56° above it. The galvanometer deflections were in accordance with Stephan's fourth power law of radiation.

The emissivity of various surfaces commonly met with in buildings was determined.

Direct observations of the temperature of radiant surfaces were made by fixing thermometers to the surface with plasticene, and making a correction to the observed temperature on the basis of control observations.

Low temperature radiant heat can be detected by means of the kata-thermometer, because it reduces dry kata cooling power, but has little or no effect on wet kata cooling power.

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PART II. RADIANT HEATING IN VARIOUS BUILDINGS.

BY H. M. VERNON, M.D., and M. D. VERNON, M.A., assisted by ISABEL LORRAIN-SMITH, M.A.

Introduction.

Until comparatively recently the private houses in this country were almost invariably warmed by means of coal fires, but such fires are rapidly being superseded by gas fires, and, to a less extent, by electric heaters. The heat derived from all these sources is mostly radiant. That is to say, the heat rays pass through the air without warming it. When they strike the walls, ceiling, and other structures in the room, they are largely absorbed, and in consequence these objects become warmed up and radiate out their warmth in turn. Air currents impinging on the warmed objects become heated, and help to distribute the heat through the room, so ultimately much of the radiant heat is converted into convected heat ; but the convection air currents are feeble, and usually show only slight differences in temperature. Anthracite stoves and other stoves, on the other hand, though initially giving out about half of their heat in a radiant form, set up powerful convection currents of hot air, not only from themselves, but also from the adjacent walls of the room which they heat by radiation (*cf.* (4)). In hot-water radiators, which usually consist of a number of cast iron columns side by side, only a small fraction of the heating surface can radiate directly into the surrounding space. Most of the radiation is obstructed, whilst the convected heat is nearly proportional to the surface area of the columns, and in consequence a larger fraction of the heat is distributed in convection currents than that effected by stoves. Barker (1923) calculated that for the various forms of hot-water radiator tested by him only 9 to 13 per cent. of the total transmission was by pure radiation.

It is evident that in the various forms of heating referred to the heat rays have very different opportunities of reaching the surrounding objects. The clearer the field of radiation, the less will be the convection currents of hot air created. Hence the ideal radiant surface is a flat one with no re-entering angles, and its ideal situation is the ceiling. The next best position is the upper portion of the walls, and next, the lower portion of the walls and the floor. The use of floor heating goes back to Roman times, when the whole floor was heated by hot air flues. Wall heating and floor heating by means of concealed pipes were originated by A. H. Barker (1926), who patented a system of panel heating in 1908. This system has developed greatly of recent years, and has for the most part taken the form of ceiling heating. It is

being used a good deal in offices and shops, and it has also been applied to factories, schools and private houses.

It might be supposed that the location of the source of heat in the ceiling is wrong in principle. One of us, in conjunction with T. Bedford (*cf* (6)), after testing the various heating systems installed in factories, stated that "too much stress cannot be laid on the principle of starting the source of heat as near the floor as possible." This conclusion was correct so far as concerned the systems studied, for they consisted of plenum air systems, hot-water radiators, and exposed steam and hot-water pipes. Such systems set up convection currents of warm air which, owing to their lightness, tend to rise towards the roof. Hence the temperature of the upper strata of air is always higher than that of the lower strata, and the greater the distance of the heating source above floor level the more marked is the difference of temperature. In none of the systems mentioned, with the partial exception of some of the pipe systems, was more than a small part of the heat transmitted in a radiant form, whilst with panel systems almost the whole of it is in this form if the panel is in the ceiling. With wall panels, however, it appears that only 60 per cent. or less of the heat is radiant. Griffiths and Davis (1922) made numerous observations on the relative proportions of heat transmitted by radiation and by convection, and they found, for instance, that a vertical 6-in. gas pipe, 8 ft. 8 in. in height, with an emissivity of 0·90, transmitted from 56 to 61 per cent. of its heat by radiation. This was when the pipe temperature was 35° F. higher than the air temperature. With shorter pipes the proportion of radiant heat was smaller, being 55 per cent. with a 3-ft. pipe, and 51 per cent. with a 1-ft. pipe. The loss of heat by convection is due to currents of air which rise rapidly close to the heated surface, and it is stated that the results obtained with cylinders apply to plane surfaces such as a wall panel. In these observations no attempt was made to ascertain the effect of variations in the extent of air movement in the laboratory upon the heat loss by convection, though it would certainly be substantial.

Other observations were made upon plane surfaces, 3 to 4 ft. square, which were suspended horizontally. When the surface was facing upwards, the proportion of heat lost by convection was somewhat less than when it was vertical. When the surface was facing downwards, the proportion of heat lost by convection was about two-thirds as much as when it was vertical; but these latter observations cannot be applied to what happens with ceiling panels. The experimental hot surface lost heat by convection because it created currents of hot air, which ascended to the upper strata of the laboratory. As will be shown later on, there is practically no stratum of hot air below a ceiling panel, so there can be no convection currents worth speaking of to carry away the heat. In other words, the transmission of heat must be almost wholly radiant.

The Effects of Wall Panel Heating.

It will be convenient to describe first a typical system of concealed wall panel heating which was installed in a large block of offices, because the evidence obtained there, more especially in its physiological aspect, was more complete than that obtained elsewhere. Our observations were made almost entirely in a large basement room of this block, which was placed at our disposal; but all the other offices were heated and ventilated on the same system. The room in question was 67 by 73 ft. in area, and 10 ft. in height in the middle three-fifths of the room, but only 8 ft. 9 in. high in the outer fifths. There were windows on the two longer sides, 5 ft. 10 in. by 3 ft. 8 in. in area, and the walls between them, which were 57 in. wide, contained concealed panels. They were constructed of steel pipes, of half-inch internal diameter, on the principle shown in Fig. 1. They were covered over with about ¾ in. of plaster, the surface of which was painted cream colour. Through these pipes hot water was pumped at a flow temperature of 135° to 140° F., the return temperature being about 120° F. Several series of observations on the surface temperature of one of the panels were made by putting the cone of the thermopile close to the wall, and moving it across inch by inch. The temperatures were calculated from the galvanometer deflections on the hypothesis that the emissivity of the wall was the same as that of a lamp-blacked surface (*cf.* Part I of this Report). The mean of two sets of observations is shown in Fig. 2, and it will be seen that at the edges of the panel the

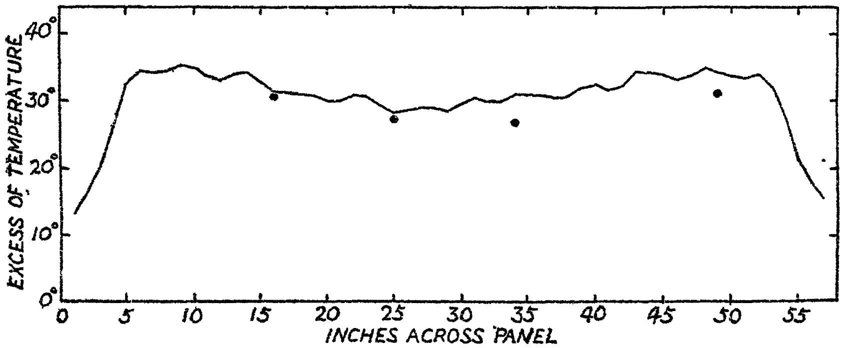

FIG. 2 Surface temperature of wall panel.

temperature was only 13° to 16° above the air temperature of the room (64° F.), but 9 in. from each edge it rose to a maximum of 35° above it; *i.e.*, its actual temperature was 99°. In the middle portions of the panel it fell several degrees, presumably because the flow of hot water was less rapid than in the outer pipes. The smaller and intermittent irregularities in the temperature curve are mostly due to the imperfect conduction and equalisation of the heat from the pipes, which were about

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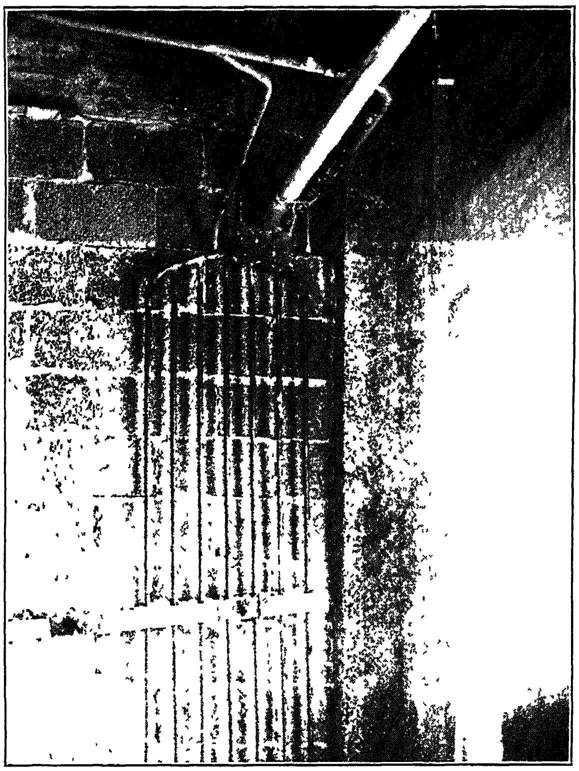

FIG 1 The uncovered pipes of a wall panel.

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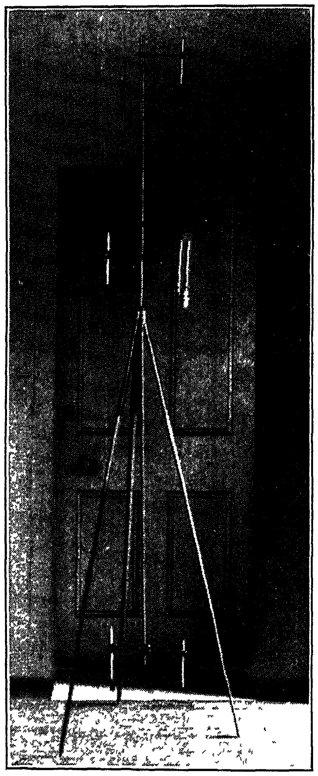

FIG. 3. Stand for supporting thermometers

$4\frac{1}{2}$ in. apart. It will be seen from the dots in the Figure that the temperatures estimated by thermometers fixed with plasticene were somewhat lower than those estimated by the thermopile, for the reason mentioned in Part I of this Report.

The wall panels projected into the room 2 ft. beyond the recessed windows. Observations on the temperature and velocity of the air currents were made systematically at four spots, A, B, C, D :—

Spot A was 3 ft. from the middle of a panel.
Spot B was 5 ft. from the middle of a window.
Spot C was 6 ft. from the edge of a panel and window recess
Spot D was 33 ft. from the panels in the middle of the room.

These observations were made with the convenient form of apparatus shown in Fig. 3. This consisted of a telescopic tripod stand, to the head of which was screwed a hollow brass tube, 36 in. in length, with one joint in the middle ; whilst another and thinner brass tube, 46 in in length, with two joints, was screwed into the head and reached towards the floor. To these rods were clamped thermometers, at a height of 7 ft. 3 in. and 0 ft 6 in. above the floor level, and a hygrometer and a kata-thermometer at a height of 4 ft. 9 in. The kata-thermometer was also used at the 6-in level. All the thermometers and kata-thermometers employed were standardised previous to use. After an investigator had made a set of kata and temperature observations at a given spot, she sat down for half-an-hour, facing panel or window, and at the end of this time recorded her sensations of warmth and of air movement according to the following scale of marks :—

Sensation of Warmth.		*Sensation of Air Movement.*	
Air felt to be much too warm	1	Very stagnant	1
,, ,, too warm	2	Stagnant	2
,, ,, comfortable	3	Medium	3
,, ,, too cold	4	Fresh	4
,, ,, much too cold	5	Very fresh	5

This scale is founded on the scale used by one of us, in conjunction with T. Bedford and C. G Warner, for estimating our sensations of the atmospheric conditions in factories (5, 6), and coal mines (7), but it is less elaborate than these scales. We did not content ourselves with registering our sensations in units, but generally assigned to them values lying between the numbers (e.g., a value of 3·5 implied a sensation of warmth lying midway between " comfortable " and " too cold " sensations). More often than not the sensations of warmth and air movement showed an inverse correspondence. For instance, " too cold " air usually felt " fresh," and " too warm " air usually felt " stagnant," but this was by no means always the case, and we invariably made independent estimates of the two sensations.

The radiant heat observations were made by the investigator (H.M.V.) after he had sat down for half an hour, in order that the

thermopile might have time to reach equilibrium with the air temperature. So far as possible, each of the three investigators made observations at the four spots A, B, C, D in the morning and in the afternoon. In the morning all the windows were kept shut, but at the end of these observations the upper lights, which were in the form of inverted hoppers, were opened to a moderate extent, and were kept open during the afternoon.

Temperature Gradients.—The mean dry bulb temperatures of the air at the four spots are shown in Fig. 4. In addition, the floor temperature, as estimated by the plasticene method, is

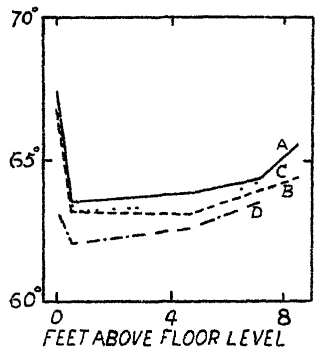

FIG. 4. Temperature gradients in office heated by wall panels.

included. It will be seen that it was 2° to 4° higher than that of the air 6 in. above it, whilst the air temperatures at spots A, B and C were almost constant at the three levels investigated, and differed only by a degree in the centre of the room. We shall see that this steadiness of air temperature is characteristic of all the forms of radiant heating investigated, and serves to distinguish them from most non-radiant forms. The gradient observations at spots A and B were carried up to a level of 8 ft. 6 in., that is, 3 in. below the ceiling, and it will be seen that even here the gradient was small. The slightly higher gradient observed at spot A (3 ft. from the panel) may have been due to convection currents of warm air rising from the panel and spreading along the ceiling. In determining the air temperatures at spot A, 3 ft. from the warm panel, care had to be taken to exclude the influence of direct radiation. A sheet of polished aluminium, 3 in. square, was fixed about 2 in. from the thermometer bulb, between it and the radiant source. This caused an average fall of 1·4° in the temperature of the exposed thermometer at the 4 ft. 9 in. level and one of 0·5° in that of the 7 ft. 3 in. thermometer, but no appreciable effect in the 6 in. thermometer, for the panel pipes reached only to within 18 in. of the floor, and also the more rapid air currents met with near the floor helped to neutralise the slight radiant effect.

Subjective Sensations in relation to Cooling Power.—The kata-thermometer observations were made at each spot by two investigators independently, in the morning and in the afternoon, and a mean taken, whilst the sensations of warmth and of air movement of the *three* investigators were similarly averaged. Altogether, 52 of these combined results were obtained, and the means of all the observations at each spot are recorded in Table I. It will be seen that the cooling power at head level (4 ft. 9 in.) ranged from 5·6 to 5·9 at the various spots, whilst at foot level (6 in.) it ranged from 6·4 to 7·0. These differences of cooling power were due in part to differences of air temperature, which was 1·3° higher at spot A (3 ft. from the panel) than in the centre of the room, and to a less extent to air velocity, which was on an average 3 ft. more per minute in the centre of the room than elsewhere. They were also due in part to the direct effect of the radiant heat on the bulb of the kata. It should be stated that, unless express mention is made to the contrary, the bulb of the kata was always unprotected by aluminium foil from the radiant heat when the cooling power was ascertained. The air temperature was taken with the thermometer both protected and unprotected. The latter value was necessary in order to permit the calculation of the air velocity. Thus at spot A the protected and unprotected temperatures at head level averaged 63·9° and 65·3° respectively, and with a cooling power of 5·6 they yielded air velocities of 14 and 18 ft. per minute. The latter is approximately correct, but we shall see later on that when the radiant heat is powerful, as from a gas fire, the calculation of the air velocity does not apply.

The sensations of warmth varied from 3·1 at spot D to 2·4 at spot A; that is, from very slightly on the cool side of "comfortable" to three-fifths of the way towards "too warm." However, this difference was due partly to the differences of air temperature, though it is true that these differences were due in their turn to the effects of the radiation. Thus the floor and other objects, such as table and chairs, were distinctly warmer at spot A than elsewhere (*cf.* Fig. 4), and they must have warmed the air slightly. The sensation of air movement varied from 2·5 at spot A (or mid-way between "stagnant" and "medium") to 3·0 at spot D, so undoubtedly the radiation from the wall panels did affect our sensations of warmth and of air movement appreciably. It is of interest to determine how far this was due to the direct effect of the radiation on the human body, and how far to indirect effects. That is to say, how far did our sensations differ at equal kata cooling powers? Before determining this point, it is desirable to indicate how our data compare with previous results. In order to make the comparison, we arranged them in order according to the sensation of warmth, and divided them into three nearly equal fractions. These fractions were averaged, together with the associated kata cooling powers, and they are plotted out on the left side of Fig. 5. The dotted lines record the

TABLE I.—*Observations in wall-panel office.*

Position.	No. of combined observations.	D B Temperature in °F at			Dry kata at			Air Velocity in ft. per min. at			W B Temp. at 4′ 9″ in °F	Wet kata at 4′ 9″	% of dry kata on wet kata.	Sensation of	
		7′ 3″	4′ 9″	6″	4′ 9″	6″	Mean	4′ 9″	6″	Mean				W'mth	Air movement
A 3 ft. from panel ..	14	64 4	63 9	63·6	5·6	6·4	6·0	18	27	23	55 5	16 8	33	2·4	2·5
B. 5 ft. from window ..	11	64·0	63·1	63·2	5·8	6·4	6·1	15	24	20	54·6	17·1	34	2·9	2·8
C. 6 ft from panel ..	12	64·3	63 4	63·2	5·6	6·6	6·1	13	28	21	54·9	16·6	34	2·8	2·9
D. 33 ft. from panel ..	15	63·6	62·6	62·1	5·9	7·0	6·4	15	32	24	54·3	17·3	34	3·1	3·0

averages of the 1,166 expressions of opinion previously obtained (*cf.* (6)) in winter time from the operatives in numerous factories, and also of the combined 2,474 opinions obtained in summer as well as in winter (the curve being labelled "mean"). These expressions were obtained in relation to the head-level kata cooling power only, and on comparing our own head-level results with the winter results of the manual workers, we see that the divergence is considerable. For instance, we ourselves found the atmospheric conditions to be "comfortable" at a kata cooling power of 5·8, whilst the operatives experienced a similar sensation at a cooling power of 6·6. This discrepancy is due partly to the fact that we ourselves were sitting down, doing no physical work at all, whilst the operatives were in many cases standing up, and were in all cases doing light manual work. Also the winter weather at the time our observations were made was distinctly milder than that experienced during the observations on the

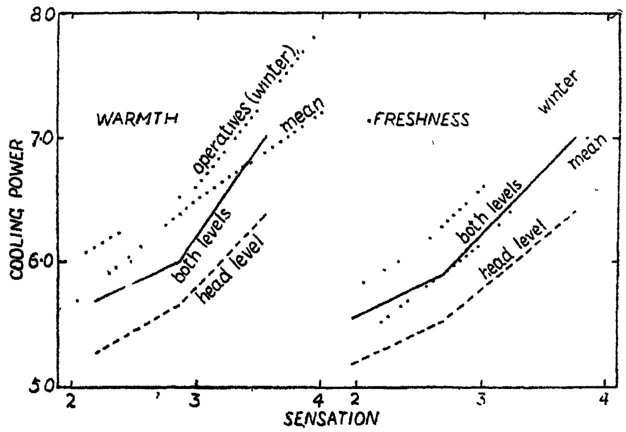

FIG. 5. Comparison between sensations experienced in wall-panel office and previous results.

operatives, and we were therefore acclimatised to a rather lower kata cooling power. It will be seen from Fig. 5 that the curve of mean kata cooling power observed by us at the combined foot and head levels agrees fairly well with the mean curve obtained with the operatives in the combined summer and winter weather, and accordingly we shall make our subsequent comparisons on the same basis. On the right side of Fig. 5 our results are plotted out in relation to sensations of freshness. For comparative purposes we have the 203 winter observations made by Bedford and Warner (*cf.* (5)) and the 432 combined winter and summer observations. These observations were made in relation to the head-level cooling power only, and we see that our present head-level observations differ from them considerably. For instance, we experienced a medium sensation of air movement at a kata cooling power of 5·8, as compared with the value of 6·6 obtained by

Bedford and Warner. The discrepancy is due in part to the same causes as those previously mentioned, for Bedford and Warner were actively employed in making kata observations at the time they recorded their sensations. It will be seen that our combined head and foot-level cooling powers are in close agreement with the combined winter and summer observations of Bedford and Warner, and accordingly we shall make our subsequent comparisons on this latter basis.

The personal equation necessarily counts for a great deal in these observations, and on plotting out our individual results we found that two of us were in close agreement, whilst the third was a distinctly " chillier " person than the other two. Probably all of us were rather chillier than the average operative, or than Bedford and Warner.

Returning to the observations made at spots A to D, we see on the left side of Fig. 6 the relationship between sensation of warmth and kata cooling power (the means for both levels). The results

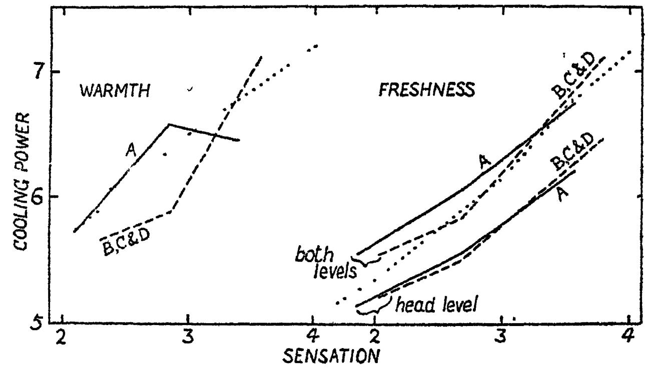

FIG. 6. Sensations experienced at wall-panel office in relation to cooling power.

obtained at spots B, C and D resembled one another, and for the sake of clarity they have been combined in a single curve. Those obtained at spot A (3 ft. from the warm panel) are plotted separately, and though the curves are rather irregular it is evident that, on the whole, a given sensation of warmth was felt at a higher cooling power at spot A than elsewhere. That is to say, a higher cooling power was compensated for by the radiation from the wall panel. However, the sensation of freshness was apparently not affected, as can be seen from the results plotted on the right-hand side of Fig. 6. Neither the head-level results, nor the combined head and foot-level results, show any consistent difference at spot A and at spots B, C and D. Still, it must be borne in mind that the radiant heat tends to lower the kata cooling power of the air slightly. Arguing from the results recorded in Part I of this Report and from other data, the cooling power at spot A was probably lowered about 0·1 unit owing to the direct radiation. It is a very small amount, but it follows that if the sensations had

been plotted out in relation to the *protected* kata cooling power, the observations made at spot A would have been slightly more divergent from those made at other spots than is indicated in Fig. 6.

The close relationship between the cooling power of the air and the sensation produced is shown by the high correlations. As the estimates of sensation were not quantitative, it was not permissible to calculate correlation coefficients, so *correlation ratios* were determined instead. Such ratios are usually somewhat larger than the coefficients, but the values show that in any case the correlation was considerable. The correlations relate to the 112 individual observations made at spots B, C and D, and it will be seen that the correlation ratio of the cooling power (at both levels) on sensation of warmth was 0·77, whilst that of cooling power on sensation of freshness was distinctly higher, being 0·88. The data on which these correlations are based are recorded in Table II.

Correlation Ratios of

Cooling power on sensation of warmth ..	0·771±0·026
Cooling power on sensation of freshness ..	0·878±0·015
Sensation of warmth on cooling power ..	0·731±0·030
Sensation of freshness on cooling power ..	0·835±0·019
Sensation of freshness on sensation of warmth	0·835±0·018

TABLE II.—*Correlation between sensations and kata cooling power of air.*

Sensation of warmth or freshness	Cooling power associated with warmth sensation		Cooling power associated with freshness sensation.		Kata cooling power	Associated sensation of warmth.		Associated sensation of freshness.	
	Mean.	Frequency.	Mean.	Frequency.		Mean	Frequency.	Mean.	Frequency.
1·6	5·55	1	5·41	5	5·20	2·58	15	2·16	15
1·9	5·83	5	5·58	12	5·55	2·67	28	2·40	28
2·2	5·59	9	5·64	12	5·90	2·87	13	2·87	13
2·5	5·69	22	5·75	19	6·25	2·77	21	2·79	21
2·8	5·80	11	5·80	11	6·60	3·36	8	3·36	8
3·1	6·08	34	6·22	13	6·95	3·24	11	3·65	11
3·4	6·76	15	6·25	15	7·30	3·52	5	3·70	5
3·7	7·69	8	6·95	8	7·65	4·30	1	4·60	1
4·0	7·79	5	7·65	8	8·00	3·85	2	4·00	2
4·3	7·65	1	7·42	3	8·35	3·55	4	4·38	4
4·6	8·70	1	8·35	5	8·70	4·08	4	4·53	4
4·9	—	—	8·70	1	—	—	—	—	—
S.d. of all observations	0·914		0·914			0·562		0·806	

In addition to tabulating the data on the basis of sensation with cooling power in association, they were tabulated on the basis of cooling power, with sensation in association. It will be seen that the ratios calculated on this basis closely resembled the others. The close correspondence between the ratios of warmth and of freshness is shown by the fact that the correlation ratio of the latter on the former was 0·835. It is to be remembered that

the correspondence is really between " warmth " and " stagnancy" on the one hand, and " cold " and " freshness " on the other, so the correlation between warmth and freshness is strongly negative.

Another method of detecting radiant heat effects, referred to in Part I of this Report, depends on the fact that the dry kata cooling power is more affected than the wet kata cooling power, and consequently the ratio of the one to the other tends to fall. We see from Table I that the ratio (expressed as a percentage) was very slightly smaller at spot A than elsewhere, but the difference is within the limits of experimental error.

Thermopile Observations.—The heat radiated by the walls, ceiling and floor of the various buildings examined was systematically tested by means of the thermopile. Two methods were used. In one of them the thermopile was fixed on a vertical rod with a pulley wheel at its base, and this was connected by a cord with a set of pulleys of various diameters, whereby it could be rotated slowly in a horizontal plane at various speeds. The speed usually chosen was one complete revolution of the thermopile in 2½ minutes. The galvanometer was read at 2½ second intervals, synchronously with the ticks of a metronome, and each experiment was continued for 5 minutes. In Fig. 7 is shown

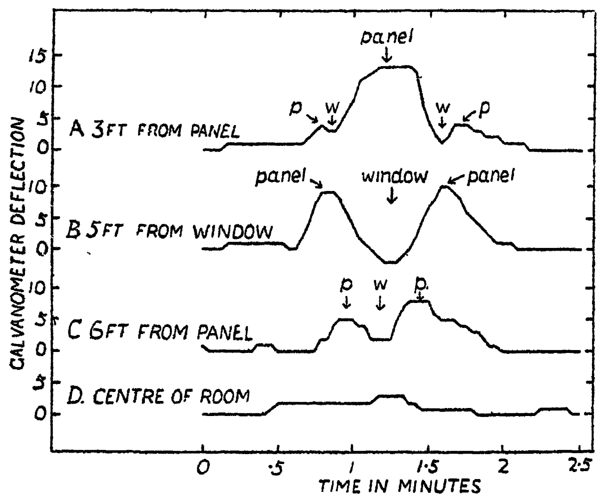

FIG. 7. Circles of radiation in wall-panel office.

the effect of a single revolution of the thermopile at spots A to D. The instrument was 4 ft. 9 in. above floor level, and it will be seen that when its cone faced a wall panel 3 ft. away, the galvanometer registered a deflection of 12·5 divisions. This corresponds to a radiant temperature (of a lamp-blacked surface) of 26° F. in excess of the air temperature. On each side of the main deflection there is a small secondary rise. due to the heat from the further wall panels, and between there are two small depressions, due to the windows. In the record obtained 5 ft.

from a window there was a distinct negative deflection when the instrument faced the window, indicating that the radiation was smaller than that from the standard tin of water (at 64° F.). The day was a mild one, and a later record taken elsewhere on a cold day (*see* Fig. 20) shows a much more marked negative effect. The panels on each side of the window caused a considerable positive deflection, so it might be thought that an observer seated at spot B would notice the very variable radiations from the hot and cold surfaces, but as a matter of fact none of us did so. At spot C, 6 ft. from the wall, the effects of two adjacent panels and the intervening windows are shown, whilst at spot D, in the middle of the room, the circle of radiation showed comparatively small variations.

The second method of testing radiation gave more useful results than the first, for it was pursued systematically, in connection with the previously described observations on sensation in relation to cooling power. After each half-hour's sitting, the investigator, having noted the galvanometer deflection when the thermopile was facing the standard tin of water, turned it N., S., E. and W., and then to the ceiling and the floor. Finally, it was turned again to the standard tin. In this way the average radiation from the surfaces to which the thermopile was turned was ascertained, and it was converted into equivalent temperatures on the basis of the calibrations given in Part I of this Report. Any small difference in the temperature of the air and of the water in the standard tin was allowed for. The results obtained at the various spots were extremely consistent, and they have been averaged in two groups ; (*a*) the morning observations, made when all the windows were closed, and (*b*) the afternoon observations, made when they were open to a moderate extent. The results are plotted out in Fig. 8, the continuous lines representing morning observations, and the dotted lines afternoon

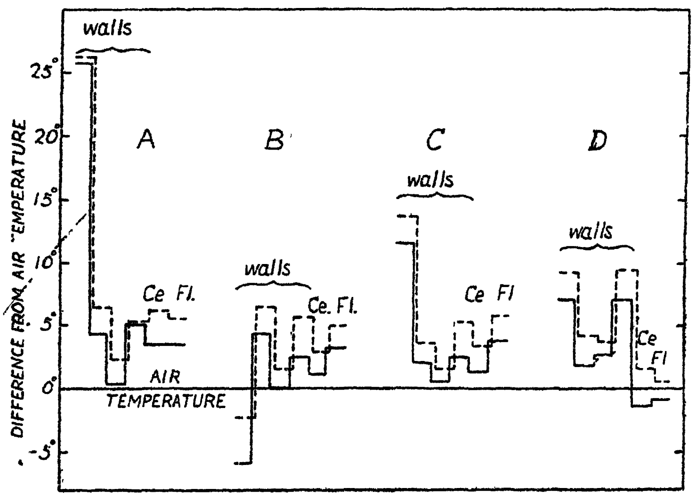

FIG. 8. Mean radiation from various directions in the wall-panel office.

observations. The observations made at spot A, 3 ft. from the panel, show that the walls, ceiling and floor were always warmer than the aii at the same spot. The mean excess of temperature ranged from 26°, when the thermopile was facing the panel, to 1° when facing the far side of the room ; for though there were wall panels there, their radiation was obstructed by desks and other intervening objects. The ceiling and the floor (labelled Ce. and Fl.) showed an excess of about 5°. At spot B, 5 ft. from the window, a negative temperature of 6° was observed in the mornings when the thermopile was facing the window. At spot C, 6 ft. from the panel, the excess of temperature induced by the warm panel was about half as great as at spot A. At spot D, in the centre of the room, the radiant temperature of the ceiling and floor was about 1° less than the air temperature in the morning, though 1° greater in the afternoon.

The mean air temperatures and mean radiant temperatures are recorded in Table III. It will be seen that, in the morning observa tions, the air temperature averaged 64·5° (at head level)

TABLE III.—*Comparison of mean radiant temperature with air, temperature in wall-panel office.*

Position.	Windows Shut.			Windows Open.		
	Air Temp. °F.	Excess of Radiant Temp. °F.	Excess R.T. except warm panel. °F.	Air Temp °F.	Excess of Radiant Temp. °F	Excess R T. except warm panel °F.
A. 3 ft. from panel ..	65·1	7·1	3·3	62·1	8·7	5·2
B. 5 ft. from window..	64·4	0·9	0·9	62·3	3·2	3·2
C. 6 ft. from panel ..	64·6	3·6	2·1	61·8	5·7	3·9
D. 33 ft. from panel ..	63·9	2·8	2·8	60·6	4·9	4·9
Mean ..	64·5	3·6	2·3	61·7	5·6	4·3

whilst the radiant temperature averaged 3·6° more. If, however, the radiation rom the warm panel is excluded from the observations made at spots A and C, the excess of radiant temperature falls to 2·3°. In the afternoon, when the air temperature had fallen to 61·7° because the windows had been opened, the radiant temperature of the room was 5·6° higher than that of the air, or 4·3° higher if the radiation from the warm panels (at spots A and C) is excluded. These afternoon observations were made after tne windows had been opened 2¼ hours on an average, and the effects of this window opening may be indicated thus :—

Fall of air temperature induced by 2¼ hours of open windows				=2·8°
Fall of radiant temperature	,,	,,	,,	=0·8°
Lag between air temperature and radiant temperature				=2·0°

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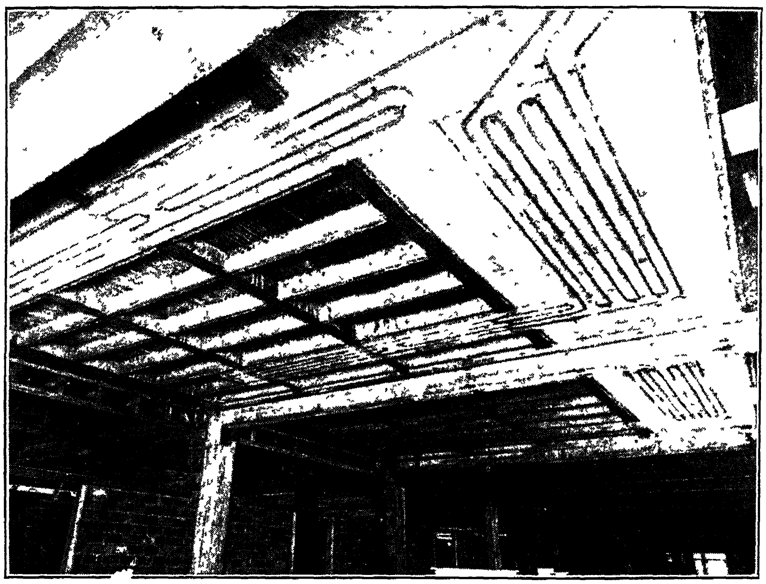

FIG 9 Ceiling panel in course of construction.

It is possible that if the windows had been open for a longer time there would have been a rather greater lag between the air temperature and the radiant temperature, but there was a fair amount of time for the attainment of equilibrium, and the mean air temperature in the latter half of the afternoon (after 3 hours of open windows) was just the same as that observed in the first half of the afternoon (after 1½ hours of open windows). In any case, the present evidence indicates that under ordinary conditions of heating and ventilation there is only a small difference between the temperature of the walls, ceiling, and floor of a room, and the temperature of the air. All the evidence to be quoted subsequently supports this conclusion.

No other radiant heat system dependent only on wall panels was investigated, but systems in which wall panels were combined with hot-water radiators, and with under-floor heating, are referred to later on.

The Effects of Ceiling Panel Heating.

Systems of ceiling panel heating were tested in four buildings of different types. In three of them the steel pipes ran as a band, 3 to 6 ft. in width, round the periphery of the rooms near the walls. Fig. 9 shows a ceiling panel system in course of construction, with the pipes partly embedded in plaster. The most complete series of observations was made by us in a large T-shaped office, which was unoccupied when we were making our investigations. We confined our observations to one arm of

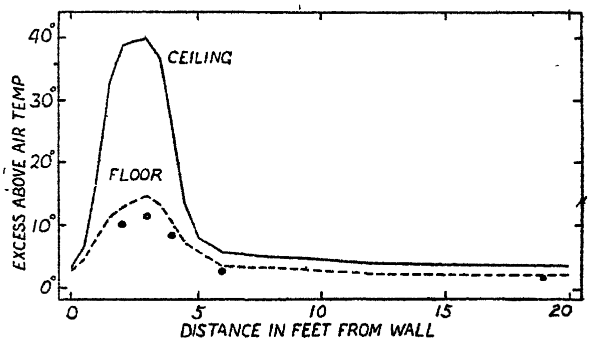

FIG. 10. Temperature of ceiling and of floor at ceiling-panel office.

the T, which was 53 ft. in length, 40 ft. in width and 10 ft. 8 in. in height. It had hopper windows on all three sides. They were 4 ft. in width and were separated from each other by 7 ft. or 4 ft. of painted wall. The temperature of the ceiling and of the floor was explored at 6 in. intervals by means of the thermopile, and the means of three sets of observations are shown in Fig. 10. It will be seen that the ceiling was warmed very little over the outer ½ ft., and did not reach its maximum till 3 ft. from the wall.

In the middle of the ceiling panel the temperature was 40° above the temperature of the room, and as this averaged 60° F., the panel temperature was 100° F. The temperature of the flow water from the boiler to the building in general averaged about 120°, and of the return water, 95°, but the temperature of the supply to this particular room could not be ascertained. The heat from the panel pipes in the ceiling of the floor below was conducted to some extent through the concrete floor and the parquet wooden flooring laid upon it, for we see in Fig. 10 that the floor temperature varied in correspondence with the ceiling temperature, and 3 ft. from the wall it reached a temperature of 74°, or 14° above the air temperature. Part of this temperature was produced by radiation from the ceiling above, but not more than about 4° of it, for we see that 7 ft. from the wall, where there can have been little or no conduction through the floor though nearly as much radiation from the ceiling, the floor temperature was only 1° warmer than in the centre of the room, which was 20 ft. from the wall. Here the radiation from the ceiling (on both sides of the room) can have been only about half as much as that at the 7-ft. region, and it raised the floor temperature 2° above the air temperature.

The temperature of the floor was ascertained at several places by the (plasticene) thermometer method, and this gave somewhat lower readings than the thermopile. In any case, the floor temperature was highest at the 3-ft. region, so we chose this as one of our points of observation (spot A). The other two spots chosen, B and C, were respectively 6 ft. and 20 ft. from the wall.

Temperature Gradients.—These were taken in the usual manner on all occasions, and the mean results, plotted in Fig. 11 and recorded in Table IV, show a most remarkable steadiness of air temperature, for there was not more than 1° F. of difference at

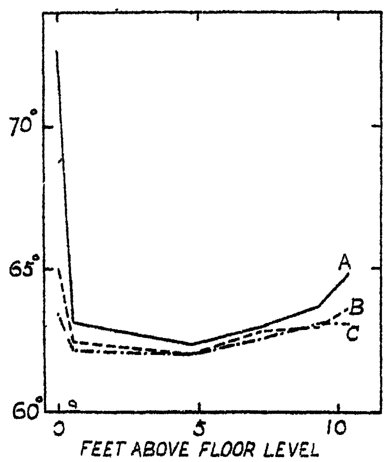

Fig. 11. Temperature gradients in ceiling-panel office.

TABLE IV.—*Observations in ceiling-panel office.*

Position	No of observa-tions.	D.B. Temperature in °F. at			Dry kata at			Air Velocity in ft. per min. at			W B. Temp. at 4′ 9″ in ° F.	Wet kata at 4′ 9″	% of dry kata on wet kata	Sensation of	
		7′ 3″	4′ 9″	6″	4′ 9″	6″	Mean	4′ 9″	6″	Mean				W'mth	Air move-ment
A. 3 ft. from wall ..	60	63·0	62·4	63·1	6·0	6·4	6·2	16	24	20	54·1	17·4	34	3·0	2·8
B 6 ft. from wall ..	33	62·8	62·1	62·5	6·0	6·5	6·2	15	24	20	54·1	17·0	35	3·1	3·0
C. 20 ft. from wall ..	32	62·6	62·1	62·2	5·8	6·4	6·1	12	21	17	54·3	16·8	35	3·0	3·0

any of the three spots, at any level up to 7 ft. 3 in. Three sets of observations were carried to within 4 in. of the ceiling, and in Fig. 11 these results are joined on to the others. They are not quite so regular, but even under the hottest portion of the ceiling panel the air was only 2·4° warmer than at head level. When taking the temperatures at the 10 ft. 4 in. level, the thermometer was fixed horizontally, with its bulb protected from direct radiation by aluminium foil; but no protection was found to be necessary when taking the temperatures at the lower levels, because the vertical position of the thermometers, coupled with their greater distance, prevented any appreciable radiation effect. When the horizontal thermometer was exposed to the direct radiation of the hot ceiling panel 4 in. above it, it registered a temperature 1·6° higher than when protected, and 1·9° higher if its bulb had been blackened by a covering of Indian ink.

Subjective Sensations in relation to Cooling Power.—When estimating subjective sensations, the investigators sat sideways to the wall or window, instead of facing it as before. The two investigators engaged on the kata and gradient observations made nearly the same number of observations as before, but the investigator engaged on the thermopile observations made only half as many. The means of the results obtained at the three spots are recorded in Table IV, and it will be seen that they are remarkably steady. The mean kata cooling power varied only from 6·2 to 6·1, and the mean air velocity, from 20 to 17 ft. per minute. The sensations of warmth and of air movement were likewise practically constant, and apparently the only response to the ceiling radiation was a very slight reduction in the sensation of air movement at spot A, directly under the ceiling panel. On dividing the data into three equal groups according to the sensations of warmth, the results plotted on the left side of Fig. 12 were obtained. It will be seen that the sensation of warmth in relation to kata cooling power was almost the same in the centre of the room and under the ceiling panel. The sensation of air movement was likewise nearly the same, as can be gathered from the data plotted on the right side of Fig. 12.

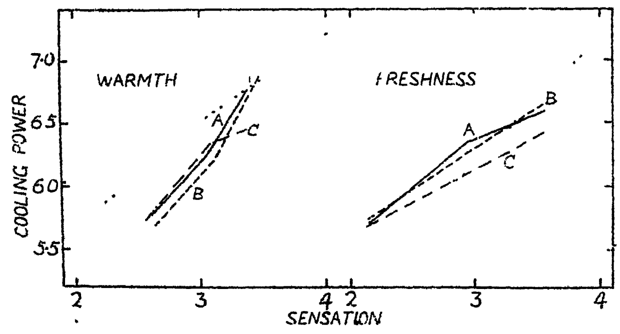

FIG. 12. Sensations experienced in ceiling-panel office in relation to cooling power.

The correlation ratio of kata cooling power on sensation of warmth was found to be $0 \cdot 698 \pm 0 \cdot 031$, whilst that of cooling power on sensation of freshness was $0 \cdot 651 \pm \cdot 037$. These values are considerably lower than those observed in the wall-panel office, where the ratios obtained averaged 0·82. Probably this is due, partly to the fact that the investigators were not so skilful in estimating their sensations, for the observations were made prior to those at the wall-panel office, and partly to the fact that the range of cooling power experienced was distinctly narrower. The data on which the correlation ratios are based are recorded in Table V.

TABLE V.—*Correlation between sensations and kata cooling power.*

Sensation of warmth or freshness.	Cooling power associated with warmth sensation.		Cooling power associated with freshness sensation.	
	Mean.	Frequency.	Mean.	Frequency.
1·6	—	—	5·90	1
1·9	5·73	2	5·66	10
2·2	5·83	5	5·70	25
2·5	5·51	9	5·95	7
2·8	5·78	21	6·19	6
3·1	6·26	59	6·43	18
3·4	6·66	28	6·52	33
3·7	—	—	6·51	8
4·0	7·65	1	6·60	3
S.d. of all observations	0·535		0·570	

Thermopile Observations.—These were made as before, by turning the thermopile to each side of the room, and then to the ceiling and the floor. The windows of the room were—as a rule—kept shut during the morning observations, but their upper lights, in the form of inverted hoppers, were opened to a moderate extent on the completion of these observations, and were kept open during the afternoon. The means of the observations are plotted in Fig. 13, and it will be seen that in the morning the radiant temperature of the four sides of the room at spot A, 3 ft. from the wall or windows, was slightly less, on an average, than the air temperature. This was because of the cold windows. The radiation from the ceiling corresponded to a temperature 16° in excess of the air temperature, and that from the floor, to a temperature of 11° in excess. The reason why the difference is not more marked is that the thermopile, when held facing the ceiling panel 6 ft above it, must have collected radiations from unheated areas as well as from the panel. When testing the floor

radiation, however, the instrument was purposely lowered from its usual 4 ft. 9 in. level to 1½ ft. above the floor, because this position was thought to yield a fairer indication of the action of floor radiation on the sensations of an individual when sitting down. Such radiations would for the most part reach only the feet and legs, and would not affect the head and body.

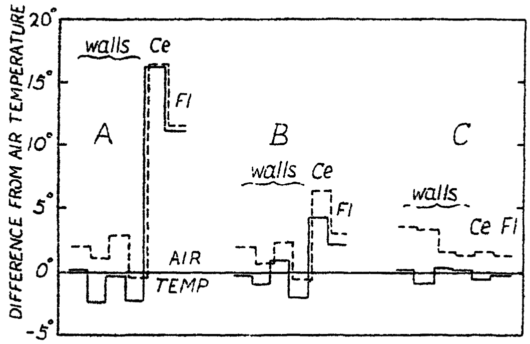

FIG. 13. Mean radiation from various directions in ceiling-panel office.

It will be seen that at spot B, 6 ft. from the wall, the radiant effect of ceiling and floor was much smaller than at spot A, whilst at spot C it was no greater than that from the sides of the room. A comparison of the mean results obtained when the windows were shut and open is recorded in Table VI. When the ceiling and floor radiation was included, the mean radiant temperature

TABLE VI.—*Comparison of mean radiant temperature with air temperature in ceiling-panel office.*

Position.	No. of observations.	Windows shut.			Windows open.		
		Air temp. ° F	Excess of radiant temp. ° F.	Excess R.T excluding direct radiation.	Air temp ° F	Excess of radiant temp. ° F.	Excess R.T. excluding direct radiation ° F.
A. 3 ft. from wall..	6	63·9	+3·8	−1·2	60·9	+5·6	+1·4
B 6 ft. from wall..	7	63·8	+0·7	0·0	60·8	+2·3	+1·5
C. 20 ft. from wall..	7	64·1	−0·2	−0·2	60·7	+2·1	+2·1
Mean ..		63·9	+1·4	−0·5	60·8	+3·3	+1·7

in the morning was 1·4° higher than the air temperature, but if the ceiling and floor radiation was excluded from the observations at spot A, and the ceiling observations from those made at spot B,

the mean radiant temperature fell slightly below the air temperature. This must have been entirely owing to the cold windows on three sides of the room. The window opening caused the air temperature to fall 3·1°, whilst the mean radiant temperature fell only 1·2°, so the radiant temperature was now 3·3° above that of the air. Even if the radiating surfaces at spots A and B were excluded, the mean radiant temperature was still 1·7° higher than the air temperature.

A comparison of the curves in Fig. 13 with those obtained in the wall-panel office (Fig. 8) shows clearly that there was a closer correspondence between the air temperature and the radiant temperature (excluding the directly heated surfaces) in the ceiling panel office than in the wall-panel office. This was due to the fact that in the ceiling-panel office the hot water flow in the pipes was never cut off. Even at the week-ends the flow temperature was kept at about 110°, so an approximate equilibrium was obtained between air temperature and radiant temperature. At the wall-panel office, however, the water flow was stopped in the afternoon, and was not started again till about 6 a.m. the next day, or at an earlier hour on Mondays in order to compensate for the absence of heat during the week-ends. Hence equilibrium between air temperature and radiant temperature was not so nearly attained. However, the difference was less than 3°, so it may be doubted if such a small deficiency as this is worth the extra expense of keeping up the hot-water flow at nights and at week-ends. The authorities at the ceiling-panel office were confident that the success of the system depended largely on the maintenance of continuous heating, whilst those at the wall-panel office were equally confident that it was unnecessary, and very wasteful. The data recorded are not sufficient to decide the question, because the two offices compared were so different in structure and in their systems of heating, but arguing from the results obtained in other buildings, which are referred to subsequently, we are inclined to think that continuous heating is unnecessary.

It was possible to turn the water on and off at each wall panel independently, and the rate at which a cold panel warmed up when the hot water was turned on, was tested on several occasions by the (plasticene) thermometer method. For instance, it was found that a cold panel warmed up 19° in the first hour after the hot water was turned on, but next day, when the water was turned off, it took three hours to fall 19° and 5 hours to fall 25°. At the end of this time its temperature was still 7° above the air temperature of the room (63°).

Ceiling Panels in another Office.—In addition to the large office above described, a smaller office was investigated in another building. It was fully occupied by the ordinary clerical staff at the time of our observations. It was 45 ft. by 33 ft. in area, and 10 ft. 6 in. in height It had three windows on one side, each 10 ft. wide and 6 ft. high, separated from each other by 4 ft.

6 in. of wall space. In the ceiling near the windows there was a warm panel about 7 ft. in width, and the record plotted in Fig. 14 shows that at one point the surface temperature was 53° warmer than the air temperature of the room (62°). The floor temperature was likewise exceedingly high, owing to conduction from the

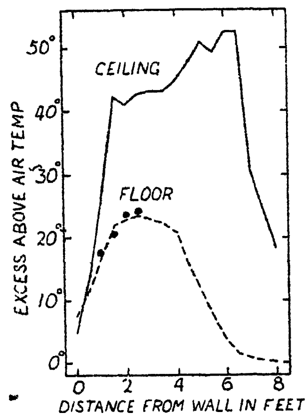

Fig. 14. Temperature of ceiling and floor at another ceiling-panel office.

panel pipes in the ceiling of the floor below, and at one spot it was 24° above the air temperature. This high temperature was confirmed by the plasticene thermometer method, as can be gathered from the dots in Fig. 14. A temperature of 20° or more above the air temperature (i.e., an actual temperature of 82°) was experienced at places 4 ft. from the walls, where some of the

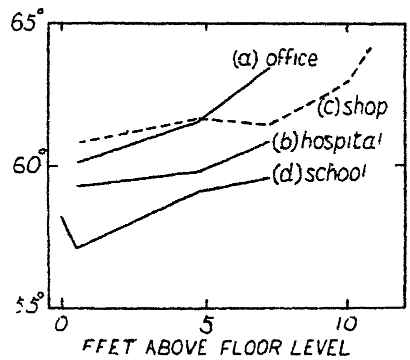

Fig. 15 Temperature gradients in various buildings.

clerical staff were seated at work, so it would have been most unpleasant for them if they had had to stand for any length of time. At least, we ourselves found it to be unpleasant after standing for five minutes. The heating had been in operation for only a few weeks, and there was some reason to suppose that

the concrete floor was not thoroughly dry, and therefore conducted heat better than it would when dry. In any case, the conduction was excessive. It will be noted that the band of floor heating was not so wide as that of ceiling heating.

The temperature gradient at positions under the ceiling panel was slightly greater than that experienced in other buildings with panel heating, as can be gathered from Fig. 15, curve (a); but the difference between the mean temperature at the 7 ft. 3 in. and the 6 in. levels was only 3·1°. The radiant temperature of the room was investigated at distances of 3, 12, and 21 ft. from the window side of the room. At each of these distances observations were made at three places distributed over the room, and from the mean results plotted in Fig. 16 it can be gathered that

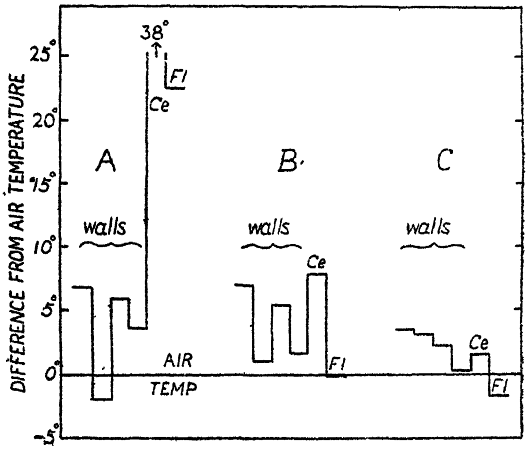

FIG. 16. Mean radiation from various directions in another ceiling-panel office.

the radiant temperature was fairly high. Excluding the ceiling and floor observations made in the A positions, it was, on an average, 3·6°, 3·8° and 1·5° above the mean air temperature (61·6°) at places A, B, and C respectively. The circumstances were most favourable for yielding a radiant temperature well above the air temperature, for nearly half of the large hopper and swivel windows were open at the time of the observations.

Ceiling Panels in a Hospital.—Of the other buildings investigated, two had ceiling panels somewhat similar in area and distribution to those already described. One of the buildings was a hospital, the wards of which were 30 ft. by 18 ft., and 11½ ft. in height. The ceiling panel, about 3½ ft. in width, extended round three sides of the room, directly above the head of the ten beds. Owing to the presence of patients we made only a brief series of observations, but we found that the temperature gradient was low. The average for three positions (3 ft. from a wall, 3 ft. from a window, and in the centre of the room) is

recorded as curve (*b*), Fig. 15. It shows a difference of only 1·6° between the temperature at the 6 in. and 7 ft. 3 in. levels. The mean radiant temperature was tested by thermopile at two places, 3 ft. from a wall and a window, and was found to be only 0·5° above the air temperature if the radiation from the warm ceiling panel was excluded, or 3·5° if it was included. This small excess of radiant temperature was presumably due to the continuous character of the panel heating, and to the fact that only one of the twelve hopper windows was open.

Another building investigated was a large shop. In some of the rooms the ceiling panels were distributed in a manner similar to that shown in Fig. 9, but we could not conveniently make observations. In the accountants' office, where we did make them, there was a panel, 4 ft. in width, extending along the outer wall above the windows. The room was L-shaped, one arm being 60 ft. long, the other, 40 ft. The arms averaged 20 ft. in width and 11 ft. in height. We made gradient observations under the panel, 2½ ft. from the wall, and obtained the average result shown in curve (*c*), Fig. 15. The temperature at the 7 ft. 3 in. level was only 0·7° above that at the 6 in. level, and even 3 in. below the hot ceiling panel it was only 3·4° above that at the 6 in. level. In determining the air temperatures near the ceiling the thermometers were protected from direct radiation by aluminium foil. The room was fully occupied at the time of our observations, and the windows were open to a moderate extent.

Ceiling Panels in a School.—The remaining building investigated was a recently erected elementary school, accommodating 400 children. There was a central block, containing cloakrooms on the ground floor and staff rooms above, and on each side were five class rooms, each 24 ft. long, 20½ ft. wide and 11 ft. high. At each end of the building was a larger room, used for arts and crafts and for laboratory work respectively. One side—the east—of the class rooms consisted of swing doors which could be fastened back against one another, so as to throw the room open to the outside air. Each door contained a hopper window, and there were swivel windows in the wall above. On the west side there were three windows, each 6½ by 3 ft., containing a hopper at the bottom and a swivel window at the top. The warm panel almost covered the ceiling as it extended to within 6 in. of each partition wall and to within 2½ ft. of the window walls. The flow water was kept at a temperature of 135° in cold winter weather, and this maintained the ceiling panel at a temperature of about 100°. During our visit, which was in rather mild weather, its temperature in the room tested was only 87°, whilst the air temperature was 58°

During a period of 3½ hours the temperature gradient was determined three times at a spot in the middle of an unoccupied room, and at other spots 3 and 8 ft. from the west windows. The mean air temperatures were 59·1°, 58·5° and 58·2° respectively,

and the gradients were similar, so the means for the whole room are alone recorded (curve (*d*), Fig. 15). It will be seen that the floor temperature was a degree warmer than the air immediately above it, but was rather colder than the air at higher levels. Also the mean radiant temperature of the room, excluding the warm ceiling, was only 0·7° above that of the air at head level. During the time these observations were made the windows were kept shut, whilst in the occupied class rooms it was customary to keep a good many of the hopper windows open. However, the loss of heat produced by the window ventilation was compensated for by the heat from the bodies of the 40 children who occupied each room. In each class room there was a thermometer fixed to a cupboard, and this was read by a member of the staff every day at the times when the children started work (9 a.m. and 1.30 p.m.). These temperatures averaged 58° in November and December, 1926, and in January, 1927, whilst they fell to 57° in February and March, 1927. The supply of panel pipe water to the various rooms had not been well adjusted, and their mean winter temperature varied between the extremes of 55° and 59°. Observations made during the middle of the morning and afternoon sessions showed a temperature about 2° higher than the 9 a.m. and 1·30 p.m. temperatures, so it may be said that the mean winter temperature of the class rooms was nearly 60°. This was considered quite satisfactory by the management.

Under-Floor Heating.

The system of under-floor heating adopted in the schoolrooms recently designed by G. H. Widdows for the Derbyshire County Council has already been described (*cf.* (6)). The heat was supplied by hot water pipes, and the few tests made showed a floor temperature of 71° to 80°, and an air temperature of 57°. In the course of the present investigation we had an opportunity of testing the more elaborate system installed in the new cathedral at Liverpool. Here almost the entire floor space consists of a double floor enclosing a system of shallow ducts, about 12 in. by 9 in. in cross section. Warmed air from stoves situated under the centre of the building is circulated through these ducts by means of a centrifugal fan. The system of ducts is a closed one, the same air being continually circulated. Above the ducts is a 3½ in. air space, covered by a thin layer of material which supports the marble floor. The air is usually delivered into the main ducts at a temperature of 150°, whence it passes to series of lateral flow and return ducts. These run close to one another in order to equalise the distribution of heat.

When we made our observations the heating system was not fully on. We could not determine the temperature of the flow air, but the return air, which was tested at 10 and 11 a.m., at noon. and at 2 p.m., had a temperature of 81°, 95°, 90°, and 87° respectively. The main observations were made in the central space of the Cathedral, in a line between the N.E. and S.E. transepts, but

6 ft. to the west of the middle line. Temperature gradients were taken at intervals, and were very consistent. The means of 9 sets are plotted in the lowest curve in Fig. 17. The curve shows

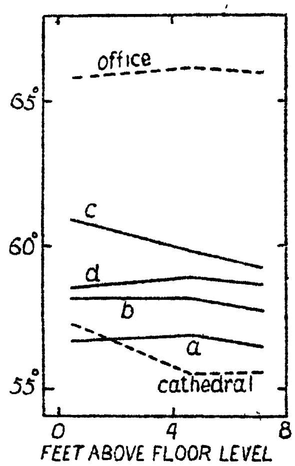

FIG. 17. Temperature gradients in various buildings.

that the temperature at head level was 1·8° lower than at foot level, whilst there was practically no difference between head-level and 7 ft. 3 in. level. A repetition of the observations in the S.E. transept showed similar temperatures; they averaged 57·8°. 55·9° and 56·1° at the three levels.

The floor temperature of the nave was determined by means of the thermopile at regular intervals opposite to each chair in a line extending from 5 ft. to 34 ft. from the centre, and it will be seen from Fig. 18 that it varied from 14° to 4° above the air

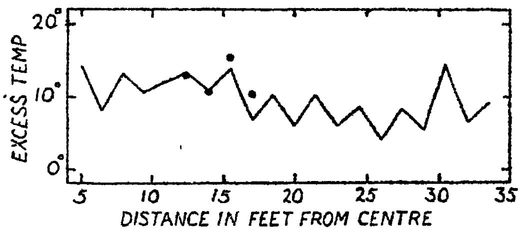

FIG. 18. Floor temperature in nave of cathedral.

temperature (56°). The zig-zags of temperature are due to the alternation of the flow and return ducts. The (plasticene) thermometer temperatures taken agree fairly well with the thermopile temperatures and they show that the floor temperature was not far short of 70°, which is the figure aimed at by the authorities. This temperature appeared to be quite pleasant to the feet during the hour or two for which the cathedral service usually lasts, for the soles of the feet are tilted up or are resting on footstools for the greater part of the time.

A system of floor heating combined with wall panel heating was investigated briefly at a huge block of offices, in which it was installed seventeen years ago. It is said to have proved quite satisfactory, though it has several features which have not been copied in recent installations. The under-floor heating is effected by a hot water pipe running round each room at a distance of about 4 in. from the walls, whilst the panels consist of coils of pipes running in the space beneath the window sills and the floor, covered with an iron casing. We investigated the system in an unoccupied office 31 ft. by 21 ft. in area, and found that the composition floor close to the walls had a temperature of 84°; but at a distance of a foot from the wall the temperature was practically normal, so it would not be unpleasant to the feet. There were three wall radiators, each 6 ft. by 3 ft., with a surface temperature of about 85°. As the day was a fairly mild one, and all the windows were shut, the air temperature of the room was too high. Observations made at four spots gave the mean temperature gradient shown in the uppermost curve of Fig. 17. It will be seen that it kept approximately at 66° at all three levels.

Electric Heating at Floor Level.—It is convenient to describe here a system of electric heating which was neither an under-floor system or a purely radiant system, though it resembled such systems. It was installed in a drawing office, 140 ft. by 45 ft. in area. Metal tubes, 17 ft. long and 2 in. in diameter, ran in front of each of the benches (which were placed transversely to the length of the room), and $1\frac{1}{2}$ in. above the floor, i.e., practically at floor level. The current running through these tubes heated them to a temperature estimated to be about 270° F., and a considerable proportion of the heat derived from them must have been radiant. In addition, there were two lines of tubing running just under the huge skylight, which occupied about two-thirds of the roof on its northern aspect. As well as this skylight, the office had 23 windows on each side, 7 ft. high and 31 in. wide. The temperature gradient was measured at four positions which were situated (*a*) 4 ft. from the windows and walls, (*b*) 11 ft. from them, on the south side, under the solid roof, (*c*) 11 ft. from them, on the north side, under the skylight, (*d*) 18 ft. from them, near the central gangway. Sets of four or five observations were made in each of these positions, and the average results are recorded in Fig. 17. It will be seen that the temperature was nearly steady at the three levels, except in position (*c*), under the skylight. Here it was 1·7° warmer at foot level than at 7 ft. 3 in. level, owing to the cold down draughts which were not completely neutralised by the hot tubes under the skylight. All the temperatures were rather low because it was an exceptionally cold day, but there can be little doubt that this system of electric heating gives as even a distribution of heat as any panel system.

Panel Heating in Factories.

As far as we are aware, no factory at present exists with a typical system of panel heating, though one is in course of erection. The saw-tooth roof of this factory contains two longitudinal strips of panel pipes, each about 3½ ft. in width, and in order to prevent loss of heat to the outside by conduction, the panels are insulated by a 2-in. layer of cork, a slab of asbestos slate, a 2-in. air-space, another slab of slate with a 3-in. air-space, and then a boarded roof.

At a large shoe factory a system of uncovered wall panels was installed in several of the workrooms, and since it has proved quite satisfactory, we devoted a considerable amount of time to its investigation. Most of the observations were made in the *closing* room, which is 273 ft. by 47 ft. in area, 12 ft. high at the eaves, rising to 21 ft. in the centre. It accommodates over 400 women, who sit at benches and sew the uppers of shoes by means of electrically-driven machines In Fig. 19 two of these benches are shown, one of them facing the windows. On the walls between the windows are seen from left to right (*a*) a metal covering, which surrounds a hot-water gill radiator. A current of air, derived from an opening in the bottom of the adjoining window, passes over this and is discharged into the room at a height of 8 ft. above floor level. (*b*) A wall panel radiator, 74 by 16 in. in area, which is fixed at a distance of 2 in. from the whitewashed wall. It will be seen that this panel is ribbed, the ribs containing small pipes which connect the large vertical pipes on each side. Between the ribs is a thin layer of cast-iron. (*c*) A blank wall, with a hot water pipe running up the middle. This system of alternating covered radiators, exposed panels, and blank walls was repeated the whole way round the room. In addition there were five 2¾ in. hot water pipes running the length of the room, 12 ft. above the floor and one third of the distance between the sides and centre of the room, but they were kept at a considerably lower temperature than the panels and radiators.

The window benches were rather narrow, and the women and girls who sat at them, leaning over their machines, had their heads within 2 ft. of the panels and covered radiators. The windows were recessed a foot, and a girl sitting opposite to one of them experienced a radiation differing considerably from that experienced by a girl sitting opposite a panel. Records obtained by rotating the thermopile horizontally at head level, at the rate of one revolution in 2½ minutes, are shown in Fig. 20. In curve A the thermopile was 2 ft. from a panel, which had a temperature of 118° F. when tested by the (plasticene) thermometer method. The thermopile indicated a temperature of only 110°, because the panel was too narrow to fill the field covered by the thermopile cone. When turned to one of the windows on either side of the panel the thermopile indicated a negative temperature 11° below that of

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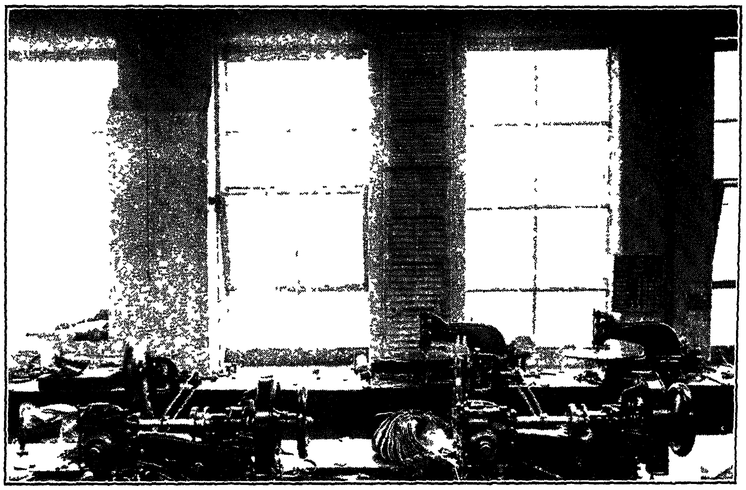

FIG 19 Workroom at shoe factory

the room (57°), whilst record C, taken when the thermopile was opposite a window, indicates a negative temperature of 13°. The day was a cold one, the outside temperature being at 30° F., and 27° lower than the air temperature of the room. Under such conditions, the window glass inside the room might be expected to have a temperature about 14° below the air temperature. The marked positive deflection of the galvanometer which preceded the negative one in curve C was due to the warm panel, so a girl sitting opposite a window experienced considerable

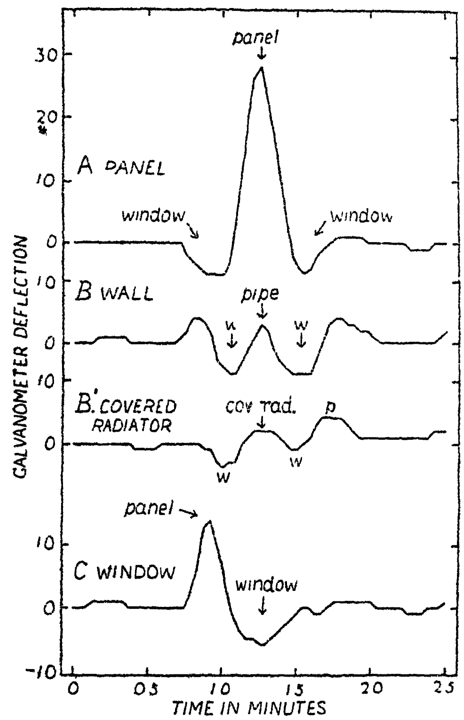

FIG. 20. Cycles of radiation in shoe factory.

variations of radiation, though not so much as one sitting opposite a panel. Curve B shows that a girl sitting opposite a blank wall experienced a fair amount of variety in radiation, owing to the hot pipe and the window on either side, whilst curve B′ shows that a girl sitting opposite a covered radiator experienced the least variation of all. However, she experienced more variation than the girls who sat at any of the benches in the other parts of the room except those who had their backs to the window-bench girls. This was proved by taking a number of thermopile records in various positions.

Subjective Sensations.—In order to ascertain the influence of the variable radiation on the sensation of warmth, the girls were questioned systematically during the times that the kata-

thermometer observations were being made by the investigators. The girls have been separated into five groups, according as they were sitting (A) 2 ft. from a warm panel, (B) 2 ft. from a wall or covered radiator, (C) 3 ft from a window, (D) at one of the inner benches, 6 to 10 ft. from the windows and walls, and (E) in the middle of the room, 22 ft. from windows and walls. Altogether 356 answers were obtained, in 78 per cent. of which the room temperature was said to be "comfortable." This neutral reply was probably genuine in the great majority of instances, and was not made with the idea of avoiding trouble, for the investigators were on quite friendly terms with the girls.

TABLE VII.—*Sensation of warmth experienced by operatives.*

Position.	No of sensations experienced	% of sensations experienced					Dry kata at 4′ 9″	D.B Temp at 4′ 9″ in °F	Air velocity at 4′ 9″ in ft. per min.
		Much too warm	Too warm	Comfortable.	Too cold	Much too cold			
A. 2 ft. from panel ..	75	3	20	68	8	1	5·7	63·7	15
B. 2 ft from wall or covered radiator	32	9	9	69	13	0	5 7	63 8	16
C 3 ft. from window . .	55	0	7	82	9	2	5 7	64·1	16
D. 6 to 10 ft. from panel .. .	102	2	10	81	6	1	5 9	63 2	16
E 22 ft. from panel .. .	92	0	6	88	6	0	5 8	63·8	17
Mean .	(356)	3	10	78	8	1	5 7	63 7	16

In a previous investigation (6), 71 per cent. of the 2,474 answers obtained from the operatives in a number of factories were similarly neutral. Of the other replies obtained in the present instance, we see from Table VII that the girls sitting opposite a warm panel felt it to be "too warm" or "much too warm" on 23 per cent. of all occasions, as compared with a value of 18 per cent. for the girls sitting at spot B, and of 6 to 12 per cent. for those sitting elsewhere. Hence it might be thought that the radiation from the warm panel had an appreciable effect on subjective sensations, but it will be seen from the data recorded in Table VII that the air velocity and kata cooling power near the panel were slightly smaller than the average values observed at the other spots. We shall see that after making due allowance for these differences the radiation from the panel had no appreciable subjective effect.

Two of the investigators (M.D.V. and I.L-S.) noted down their sensations of warmth in the usual manner, after sitting for half-an-hour 2 ft. from a warm panel, 2 ft. from a wall or covered radiator, or 3 ft. from a window. They had previously made kata observations at head level only, by putting the tripod stand on the bench at approximately the positions where their heads came during the subjective observations, whilst the kata values recorded in Tables VII and VIII were taken just at the side of the benches. The results recorded in Table IX indicate that whilst a sensation of 3·0 (that is, exactly "comfortable") was experienced when

TABLE VIII.—*Observations on operatives in shoe factory.*

Position	D B. Temperature in °F at			Dry kata at			Air Velocity in ft per min at			W.B. Temp at 4′ 9″ in °F.	Wet kata at 4′ 9″	% of dry kata on wet kata.	Sensation of w'mth
	7′ 3″	4′ 9″	6″	4′ 9″	6″	Mean	4′ 9″	6″	Mean				
A 2 ft from panel	65·1	63·7	63·3	5·7	6·3	6·0	15	23	19	54·3	16·9	34	2·8
B. 2 ft from wall or covered radiator	64·8	63·8	63·1	5·7	6·3	6·0	16	22	19	53·9	17·4	33	2·8
C 3 ft from window	64·9	64·1	63·5	5·7	6·3	6·0	16	24	20	54·5	17·0	34	3·0
D 6 to 10 ft from panel	64·3	63·2	62·6	5·9	6·6	6·2	16	26	21	53·7	17·0	35	2·9
E 22 ft from panel	64·7	63·8	62·5	5·8	6·5	6·1	17	24	20	54·6	16·7	34	3·0

sitting opposite a window, wall or radiator, one of 2·7—that is one third of the way towards "too warm"—was experienced when sitting opposite a warm panel. However, this effect was due to the higher air temperature and lower air velocity, for they, combined with the direct radiation effect, yielded a distinctly lower kata cooling power than at the other places. The greater reduction

TABLE IX.—*Sensation of warmth experienced by investigators.*

Position.	No. of sensations experienced.	% of sensations experienced. Much too warm	Too warm.	Comfortable	Too cold	Much too cold.	Mean sensation of w'mth	Dry kata at 4′ 9″	D.B Temp at 4′ 9″ in °F	Air Velocity in ft. per min at 4′ 9
A. 2 ft. from panel.. ..	53	4	34	56	6	0	2·7	5·7	63·3	14
B 2 ft from wall or covered radiator	28	0	18	68	14	0	3·0	5·9	62·7	15
C. 3 ft from window ..	24	0	12·5	75	12·5	0	3·0	6·3	62·1	19

in the kata cooling power than that met with in the observations on the operatives was due, not only to the fact that the apparatus was 6 in. nearer to the panel, etc., but also because the panel happened to be hotter. It averaged 108° in the observations of the investigators on themselves, as compared with 101° in those on the operatives.

In order to make due allowance for the differences of cooling power experienced at the various spots, the sensation data of the operatives and of the investigators (in relation to the cooling power at head level only) were divided up into three groups, and the associated cooling power determined. In the investigators' data the groups were of approximately equal size, but in those of the operatives, all "comfortable" sensations were put in one group, and all sensations of too much warmth or cold in two other groups. The mean results are plotted out in

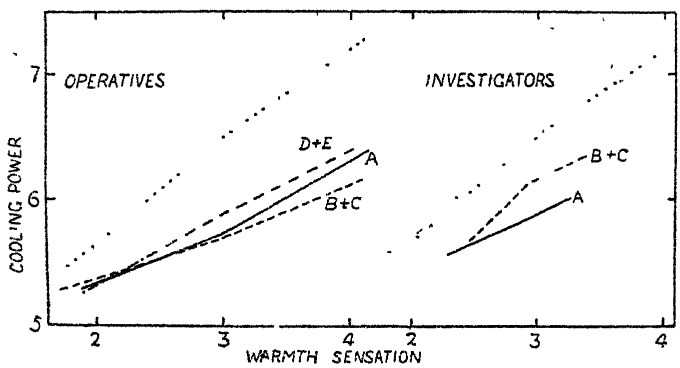

FIG 21. Sensation of warmth experienced at shoe factory in relation to cooling power.

Fig. 21, those obtained at spots B and C, and those at spots D and E, being combined for the sake of clarity. It will be seen

that when arranged in this form the operatives' data do not indicate that the relationship of sensation of warmth to kata cooling power was appreciably different at spot A, opposite the panel, and at other spots. The investigators' data even show that a given sensation was produced at a rather higher cooling power when the subject sat at spots B and C than when sitting at spot A. Hence we must conclude that the small subjective effect which was undoubtedly experienced by operatives and investigators when sitting opposite the panel was due rather to higher air temperature and lower air velocity than to direct radiation.

It will be noted that the slope and position of the curves in Fig. 21 are fairly similar for the investigators and for the operatives, with the exception that the investigators' data have a narrower range. This is entirely owing to the different method adopted for dividing up the two sets of data (viz., three equal groups in one case, and unequal groups in the other). The main significance of the similarity is that it affords a proof of the approximate accuracy of the method adopted by the investigators of sitting down for only half an hour before recording their sensation of warmth, instead of for the two hours or so which represented the average time for which the operatives had been exposed to the various forms of heating.

It is noticeable that the operatives differed a great deal in their sensations from the operatives formerly questioned. They experienced a " comfortable " sensation of warmth at a cooling power of 5·7 to 5·9, as compared with the one of 6·5 (or 6·6 in winter) which was formerly observed. This discrepancy is due partly to the fact that all of them were sitting at work, and the work itself was lighter, on the average, than that of the other operatives. Still, this explanation does not account for all the difference, so we must conclude that the present group of operatives had become acclimatised to a lower cooling power and a higher air temperature than those previously tested.

The correlation ratio of sensation of warmth on cooling power was found to be $0 \cdot 599 \pm \cdot 042$ in respect of the investigators, and only $0 \cdot 401 \pm \cdot 030$ for the operatives. The low value obtained for the operatives was due in part to the rough classification adopted (only whole units of sensation being recorded), and probably also to their lack of skill in interpreting their sensations. The ratio obtained by the investigators was rather smaller than that obtained at the ceiling-panel office, perhaps for the same reason of lack of skill, for these observations were made previously to those in the office.

Temperature Gradients.—Information about the temperature gradients, wet kata cooling power, etc., in the various positions is recorded in Table VIII. The gradients are somewhat larger than those observed in most panel heated rooms, but this is only to be expected, for over half the heating in the room was

of the convection type, and the hot air from the covered radiators was delivered into the room at a height of 8 ft. above floor level.

Exposed Panels for auxiliary Heating.—Considerably over half of the heat derived from the exposed wall panels above described must have been converted into convected heat, because the panels heated the adjacent walls and thereby set up additional warm air currents. At another boot and shoe factory where investigations were made by us, some panels of the same type were suspended in mid-air, and in consequence yielded about half of their heat in a radiant form. They were placed in the closing room of the factory (Factory A) previously described (6), because the heating was considered to be inadequate in the early mornings. The room, 140 by 46 ft. in area, had twelve of these panels, each 7 ft. by 16 in. in area, and they were suspended 9 ft. above floor level, with the ribs running vertically. The hot water supply to these panels was turned on at 5 or 6 a.m., together with that to the ordinary hot water radiators, but it was turned off when the air temperature of the room reached 60°. When we arrived at 9 a.m. the panels were only slightly warm, but the flow of hot water to the radiators was kept on all day. The temperature of this closing room was recorded continuously by means of a thermograph, and in Fig. 22 are

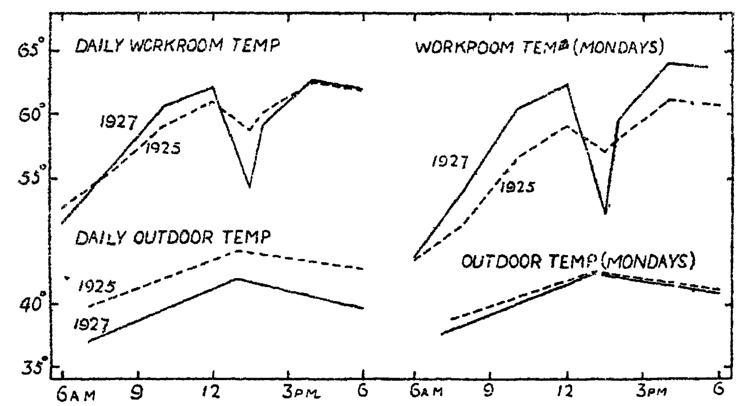

FIG. 22. The effect of introducing auxiliary panel heating in shoe factory

shown the mean diurnal variations in temperature on working days in the months of January and February, 1927. For comparison purposes the corresponding variations in 1925 are recorded, when the heating system was exactly the same except that there were no panels. The outside air temperature, calculated from the records of the Meteorological Office, is also indicated, and it will be seen that though it was about 3° colder in 1927 than in 1925, the temperature in the closing room at 10 a.m. was 1·7° higher. On Monday mornings, when it is difficult to raise the temperature to its normal level because the furnaces have

been banked up during the week-end, the difference was more marked, for the temperature at 8, 10 and 12 was 54·2°, 60·4° and 62·5° respectively in 1927, as compared with 51·5°, 56·7° and 59·2° at the corresponding hours in 1925.

The radiant temperature of the room was observed at various places distant 3 ft. and 16 ft. from the windows, and as the results obtained were similar, they have been combined. It is of interest, however, to compare the morning with the afternoon observations, for we see from Fig. 23 that the latter, which are

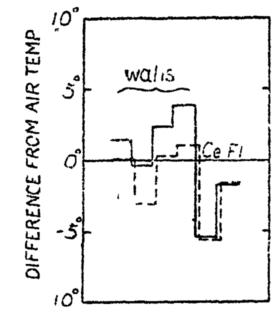

FIG. 23. Mean radiation from various directions in shoe factory.

recorded as a dotted line, show a distinctly lower radiant temperature than the former. The mean was, in fact, 1·5° *lower* than the mean air temperature (64·8°), whilst in the morning it was exactly the same as the air temperature. Eight sets of observations were made in the morning and six in the afternoon, and the temperature difference was found to be 2·4 times the probable error of the difference. Hence it may be significant. This difference is presumably due to the fact that in the morning the walls, ceiling and floor had received a good deal of radiant heat from the warm overhead panels, whereas this radiant effect disappeared by the time the afternoon observations were made, and in consequence the temperature of the walls, etc., fell below the air temperature. We shall see in the next section that under some conditions the temperature of the walls of rooms heated by hot-water radiators shows considerably more lag on the air temperature than that observed in the present instance.

The Effects of High Temperature Radiation.

The chief novelty of the panel system consists in the provision of large surfaces radiating at a comparatively low temperature. How do such systems compare in their effects on the sensations with high temperature radiation such as is produced by coal fires and gas fires? In them the radiant surface may have a temperature of 2,000° F. instead of one of 100°, and their excess radiation, over that of surrounding objects, may be a thousand times greater.

In order to obtain results which could be directly compared with those previously described, two of the investigators (H.M.V. and M.D.V.) carried out series of tests in three rooms of the same size (18 ft. by 15 ft.), one of which was heated by a gas fire, another by a coal fire, and a third by an anthracite stove. The tests were made near the middle of the room, 7 to 9 ft. from the radiant source,. and observations of temperature gradients and radiant heat were made at intervals during the morning, while the room was gradually warming up. The first series of curves in Fig. 24 shows the effect of a gas fire, with a radiating surface

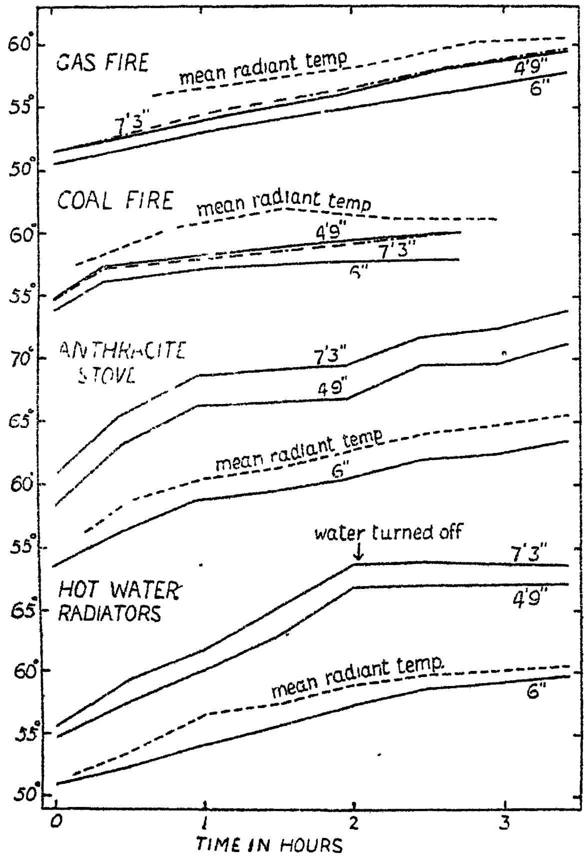

FIG. 24. The effects of various systems of heating on air temperatures and radiant temperatures.

13 by 10 in. It will be seen that in three hours the temperature rose 7°, but the temperatures at the three levels (7 ft. 3 in., 4 ft. 9 in., and 6 in.) ran closely parallel, and never differed from one another by more than 2°. The mean radiant temperature of the walls, ceiling and floor (with the exception of the wall containing the gas fire) was, however, about 2° above that of the air. The

second series of curves in Fig. 24 was obtained in a room heated by a coal fire which was glowing intensely during most of the morning. Here again the air temperature differed only by about 2° at the various levels, whilst the radiant temperature was about 2° higher. The third set of curves was obtained in a room heated by an anthracite stove, and they show a very different picture. The air temperature of the 7 ft. 3 in. level was about 10° higher than that at floor level, whilst the mean radiant temperature was about 5° lower than the air temperature at head level. These differences would have fallen somewhat if the temperature of the room had been allowed to remain steady instead of rising, but the lowest set of curves in Fig. 24 suggests that there would never have been at all a close correspondence between air temperature and mean radiant temperature. These results were obtained in a room 24 by 14 ft. in area, which was heated solely by two hot-water radiators. They averaged 24 in. in height and 25 in. in width, and stood one at each end of the room. It will be seen that after two hours of heating, the temperature of the air at 7 ft. 3 in. was 11° higher than that at foot level. The radiators were then turned off, but 1½ hours later there was still a temperature difference of 9°. The mean radiant temperature was 8° below the (head-level) air temperature after the two hours' warming up, and 7° below it after 3½ hours. Probably the difference would have fallen to about 5° in course of time, but the actual figure depends on a number of considerations, such as thickness and composition of walls, extent of window ventilation, and so on. Arguing from the present observations and from those described previously, it may be concluded that with systems of radiant heating, whether by low temperature or high temperature radiation, the transference of heat from the walls, ceiling and floor of rooms which have been heated by direct or reflected radiation is so rapid that the air temperature usually lags only 1° to 3° on the mean radiant temperature (excluding the radiant source). Evidence relating to systems which heat chiefly by convection (e.g., hot-water radiators) is insufficient to warrant a definite conclusion, but there can be no doubt that the transference of heat from warm-air to cool walls must be slower than the transference of heat from warm walls to cool air. The observations made (in the afternoon) at a boot and shoe factory heated by hot-water radiators showed a lag of only 1·5°, but the whole of the effect due to the early morning radiation from the panels may not have worn off. In the light of these observations and of those just described it seems likely that the average lag is not more than 5°, and is probably less.

The contrast between the effects of a radiant system of heating, such as a coal fire, and a hot-water radiator system, is well brought out by the two curves in Fig. 25. They show the mean radiant temperature of three sides of a room, of the ceiling, and of the floor, during the course of a morning's observations, as compared

with the air temperature at head level. In the one case all the radiating surfaces are warmer than the air, and in the other case all are cooler, the floor being nearly 10° cooler.

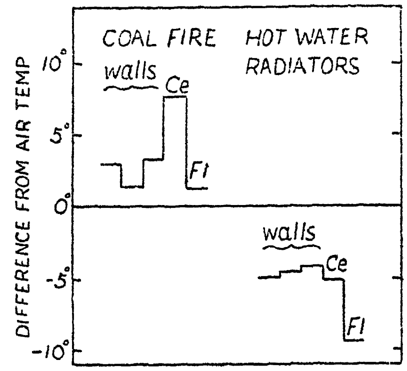

FIG. 25. Comparison of radiation in rooms heated by coal fire and by hot-water radiators.

Subjective Sensations in relation to Cooling Power.—When estimating the air temperatures in the rooms heated by gas fire, coal fire or stove, the thermometers were protected from direct radiation by means of aluminium foil, whilst the kata-thermometer was unprotected. The effect of protection on both instruments is considerable when the radiant source is a gas fire or a coal fire. For instance, the average effect of the gas fire 9 ft. distant, on the instruments fixed at head level was found to be :—

	Temperature	Kata Cooling Power. Dry.	Wet.	Per Cent.	Calculated Air Velocity.
Instruments protected from radiation	59·5°	6·04	17·4	35	10 ft.
Instruments unprotected ,, ,,	62·0°	5·35	16·9	32	7 ft.

It will be seen that the radiant heat lowered the dry kata 0·7, but it had a smaller influence on the wet kata, so the ratio of the one to the other was reduced from 35 per cent. to 32 per cent. At foot level the radiation was considerably less than at head level, and the effect was not half as great. The air velocity, when calculated from the readings of the unprotected instruments, was distinctly lower than when calculated from those of the protected ones. As it is essential to observe the cooling power of the unprotected kata because it yields a better measure of the atmospheric conditions in relation to subjective sensations, it is necessary to determine the cooling power of the protected kata in addition, if an estimate of air velocity is desired.

In determining the effect of radiant heat on the sensations, the data obtained in the gas fire and coal fire observations were grouped together as they closely resembled one another. The 24 observations made were divided into three equal groups according to the sensation, and the averages of these three

groups are plotted in Fig. 26. For purposes of comparison, the data obtained (by H.M.V. and M.D.V. only) in the office with the wall-panel heating are likewise plotted, and it will be seen that the gas and coal fire data differ considerably from the office data. They show, for instance, that a " comfortable " sensation of warmth was experienced at a cooling power of 6·7 as compared

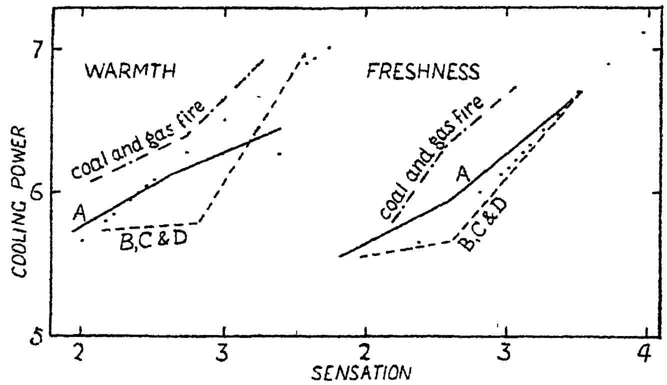

FIG 26. Comparison of sensations produced by coal and gas fires, and by panel heating.

with a cooling power of 6·3 when sitting 3 ft. from the wall panel at the office, and of 6·1 when sitting elsewhere in the office. Again, the data show that a " medium " sensation of air movement was likewise experienced at a cooling power of 6·7, when exposed to gas and coal fire radiation, as compared with cooling powers of 6·3 and 6·1 in the office.

In order to compare the effects of various forms of radiant and non-radiant heating, we have calculated the cooling powers, etc. (at head and foot level) of all the data obtained (by H.M.V. and M.D.V.) which correspond to a " comfortable " sensation of warmth. Of the gas and coal fire data, the 11 observations made at the highest cooling powers gave an average sensation of 3·0, and we see from Table X that this sensation was induced by an atmosphere having a cooling power of 6·7, and a temperature

TABLE X.—*Atmospheric conditions observed when a " comfortable " sensation of warmth was experienced.*

Quality of Heat.	No. of Observations	Mean sensations of		Mean observations at 4′ 9″ and 6″					
		W'mth	Air movement.	Dry kata cooling Power.		D B. air temp. in °F.		Air velocity in ft. per min	
Mostly Radiant heat 8 ft. from gas and coal fires ..	11	3·0	2·9	6·7		55·2		16	
" " " 3 ft. from wall panel ..	12	3·0	3·2	6 5		62·0		25	
" " " 5 to 34 ft from wall panel ..	71	3·0	3·0	6·3	6·25	62·8	62·6	22	21
" " " from ceiling panel at all distances	59	3·0	2·8	6 2		62·4		19	
Mostly convected heat (from anthracite stove) .	12	3 0	2·1	6·0	6·1	60·0	62 2	10	17
" " " (from hot-water radiators in factory).	26	3·0	3·0	6 2		64·3		25	

(with protected thermometer) of 55·2°. The corresponding observations made 3 ft. from the wall panel show a cooling power of 6·5, whilst the other observations made in offices with panel systems showed cooling powers of 6·3 and 6·2. Rooms heated mostly by convected heat (namely, the anthracite stove room and the boot and shoe factory with low hot-water radiators) gave cooling powers of 6·0 and 6·2, so these data appear to indicate that the ordinary panel heating did produce a very small effect, when contrasted with non-radiant heating. However, it is barely measurable, for if an allowance is made for the differences of air velocity experienced in the various rooms, it appears that a comfortable sensation of warmth would have been felt when the air in the panel rooms (excluding the position 3 ft. from the wall panel) was 0·7° cooler than the air in the convection-heated rooms. This figure is so insignificant as to be within the limits of experimental error. In the gas and coal fire rooms the air velocity (as ascertained with protected kata and protected thermometers) was practically the same as in the convection-heated rooms. Hence it follows that the high-temperature radiant heat caused a warmth sensation in the subjects of experiment corresponding to the difference of 7° observed in the air temperatures experienced under the two sets of conditions. This difference of 7°, or let us say, one of 5° to 10°, is probably the kind of figure which many people would themselves suggest as the result of personal experience, and it is evidently of a different order from the 0·7° calculated to correspond to the effects of panel heating. It means that, for a given heat supply, the occupants of gas and coal fire rooms can avail themselves of considerably more air movement and more air changes than the occupants of convection-heated rooms; but the occupants of panel-heated rooms get no such advantage.

It may be thought that the apparent insensibility of the investigators to radiant heat from panels was due to some idiosyncrasy, and that other subjects might respond differently. But the observations of Margaret Fishenden, in so far as they are comparable, offer some support to ours. Fishenden states (1926) that she found by direct experiment (of which details are not recorded), that a mean horizontal component of thermal radiation equivalent to 30 British thermal units per square foot per hour across the position of occupants in a room sustained warmth indefinitely when the room had an air temperature of 60° F. With a room at 50° the equivalent of 120 units was required. Hence 90 units corresponded to 10° of air temperature, and therefore the radiation effect induced by the 30 units employed at 60° corresponded to a rise of air temperature of about 3°.

Direct evidence of the small radiation from panels as compared with that from gas and coal fires was yielded by the thermopile observations. When the instrument was turned to a gas or coal fire 8 ft. distant, the galvanometer needle went right off the scale, and it was necessary to put the thermopile 16 ft. away from the

fire in order to obtain a reading. Multiplying the reading thus obtained by 4, so as to make it comparable with the other readings, a mean deflection of 220 scale divisions was obtained for the gas fire radiation, and one of 202 for the coal fire. Compared with these figures, the galvanometer gave an average deflection of only 12·4 scale divisions when placed 3 ft. from the warm panel in the office, so the effect of the radiation of gas and coal fires upon the thermopile was 16 to 18 times greater than the maximum effect of the panel. A deflection of 51 divisions was obtained when the thermopile was placed 10 ft. from an anthracite stove, so the effect of its radiation was four times greater than the effect of the wall panel. Again, the radiation from panels differs qualitatively from the radiation from gas and coal fires in that it is not transmitted by glass. In contrast, it was found that when the thermopile with its protecting glass was exposed to a gas fire, 70 per cent. of the radiant heat was transmitted. This must have been due to the shorter wave length of the radiations.

Practical Conclusions.

It is desirable that some opinion be advanced concerning the practical merits of panel heating as compared with other forms of heating. Such opinions as we express are founded on the fairly substantial body of evidence above adduced, but we do not claim to have had sufficient experience to warrant our coming to other than provisional conclusions, which may be modified to some extent in the light of further knowledge. We may say at the outset that we consider panel heating, or its equivalent, to have a great future, and we think that it is destined to replace to a considerable extent the systems of convection heating, such as hot-water radiators and plenum air installations, which are so much in vogue at the present day. At the same time it should not wholly replace hot-water radiators, because they have some good qualities to which panel systems cannot lay claim. The convection currents of hot air which rise from these radiators are very valuable in checking the down draughts of cold air which proceed from large windows; so a radiant heat system, if installed in a large room, ought to be supplemented by small hot-water radiators beneath each large window.

The most obvious merit of the panel system lies in the uniformity with which it effects the distribution of the heat over the room. We saw that the air temperature might not vary more than 1° or 2° at any position or level in the room, whilst hot-water radiator systems, and still more, plenum systems, may cause the air temperature near the ceiling to be 10° or 20° warmer than at foot level (*cf.* (6)). In consequence, the feet of the inmates of the room are too cold and their heads are too warm, and also there is an enormous waste of energy as the result of the overheating of the upper strata of the air. Still, this great defect can be largely overcome by placing the heating source as near the floor

level as possible. If hot-water pipes are put all round the room near the floor, or very low radiators are put in similar positions, and especially under the windows, the temperature gradient is comparatively small (*cf.* (6)). We saw above that an installation of electrically heated tubes at floor level gave a very even distribution of temperature, and at the same time gave out a large proportion of the total heat in a radiant form. However, no hot-water pipe or radiator system can give such an even distribution of heat to the occupants of a room as a ceiling-panel system, for some of them are bound to be nearer to the heating units than others, and to receive considerably more heat. Also the heating units take up floor space, and get in the way of machinery.

It is said that hot-water radiator and plenum air systems cause the air to feel much more close and stuffy than radiant systems of heating. Though this criticism is true of rooms which are overheated by convected heat systems with a high temperature gradient, we think that it applies very little to reasonably heated rooms with a low gradient, such as have been previously described (6). Rooms heated by steam radiators and steam pipes are apt to smell stuffy, because the hot surfaces have a charring effect on the dust which settles on them, but hot-water radiators and pipes do not char dust appreciably.

For what is perhaps the outstanding claim made by those who advocate panel heating we have been able to obtain little support. Barker (2) considers that the feeling of comfort in a room is measured less by the air temperature than by the amount and character of the radiation in the room, and a well-known firm of heating and ventilating engineers even goes so far as to say that "the radiant warmth from a ceiling approximates closely to the effect produced by sunshine." We have seen that with one exception (3 ft. from a large wall panel) we were scarcely able to detect the radiant heat from ceiling or wall panels, though admittedly we submitted ourselves only for half-hour periods to the influence of the radiation. Still, we saw that the women and girls at a boot and shoe factory reacted in almost the same way as ourselves, though they were exposed to the radiation for hours at a time. Probably the attribution of some mysterious vitalising quality to low-temperature radiation arises from its erroneous comparison with sunlight. the health-promoting activity of which is universally admitted. Even if it be allowed that the radiant heat from gas and coal fires is more pleasant and healthy than the convected heat derived from hot-water systems, it does not follow that similar qualities are possessed by radiant surfaces of comparatively low temperature. The intensity of the radiation is so very much smaller as to place it in a different category. Thus, parts of the heated surfaces of a gas fire have a temperature of about 2,000° F. (1093° C.), and according to the fourth power law their excess of radiation over surrounding objects at a temperature of 60° F. is 1,400 times greater than that of a surface with a temperature of 100° F. If,

therefore, we conclude that a radiant surface at a temperature of 100° F. is unlikely to have any special health-giving qualities, it is still more unlikely that any importance can be attached to the fact that with radiant heat systems the walls of a room are usually about 3° warmer than the air, whilst with convected heat systems they are a similar amount cooler than the air.

Another claim made for radiant heat systems is that they are much more economical than convected heat systems. Barker states (2) that, speaking generally, the necessary consumption of fuel is between one-half and two-thirds of that required to produce the same heating effect as with ordinary hot-water radiators. Supposing that a radiator system is so arranged as to give rise to a steep temperature gradient, it follows that, owing to the wastage of heat produced by overheating the upper strata of the air, there will be a serious reduction of economy. If, on the other hand, by installing low radiators close to the floor, an even, or nearly even, distribution of heat is attained, there is no reason to suppose that a hot-water radiator system should be substantially less economical than a radiant heat system. Indeed, a radiator system is more economical in one respect. Since it induces a lower wall temperature than a radiant system, it must lead to a smaller loss of heat by conduction through the walls. In wall panel systems there is likely to be a very much greater loss of heat by conduction than with radiator systems. Supposing that the temperature of the wall, one inch below its surface, is 110°, when the outside air is at 40°, then the loss of heat by conduction through the wall in question will be about four times greater than if its inner surface is at 60°, as with the average radiator system.

Summary.

In offices and other buildings heated by concealed panels in the ceiling or walls, there is a remarkable uniformity in the distribution of the heat, and the air temperature may be steady to within 1° F. all over the room at all levels, except that a few inches below the ceiling (in a ceiling-panel room) there may be a rise of about 2°

Owing to the radiation, the walls, ceiling and floor are about 3° warmer than the air, whilst in rooms heated by hot-water radiators the walls, etc., are about 3° colder than the air.

The effect of panel radiation on subjective sensations of warmth and of air movement was determined by sitting for half-hour periods in various parts of the room, after the atmospheric conditions had been investigated. As a result of hundreds of observations by the investigators on themselves and on the operatives at a shoe factory, it was concluded that, with one exception, the direct radiation did not cause a definite subjective effect. The exception occurred when sitting 3 ft. from a wall panel 5 ft. in width. A small effect was likewise noted when sitting 2 ft. from an exposed wall panel in a shoe factory, but this was the result of the higher air temperature and lower air velocity.

The radiation from gas fires and coal fires differs from that from panels, since it may be 1,000 times more intense (owing to the operation of the fourth power law of radiation). With such high-temperature radiation, rooms felt comfortably warm when 7° cooler than convection-heated rooms. In panel-heated rooms, however, the permissible reduction of air temperature was less than 1°.

Under-floor heating, though it produces a very even distribution of heat, is apt to be unpleasant to the feet. An equally even distribution of heat can be obtained by placing the heating source (e.g. hot-water pipes or electrically-heated tubes) close to the floor.

Hot water radiators of the ordinary type cause an uneven distribution of heat, and a considerable temperature gradient; but they are valuable for checking the down draughts from large windows, which arise even in panel-heated rooms.

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PREFACE.

The difficulty of obtaining accurate knowledge of the effects of hours of work of different length or arrangement, whether this is attempted by a comparison between the different establishments simultaneously or between consecutive periods in the same establishment, has been emphasised in the Board's Seventh Annual Report. It is, in fact, almost impossible to arrive at definite conclusions on the general problem unless the variations in the conditions studied are very great, as, for instance, during the War, when it was possible to explore the effects of a working week which sometimes ranged between the extremes of 77 and 56 hours, and in 1919–20 when a heavy curtailment in the weekly hours of work occurred throughout industries generally. Opportunities, nevertheless, sometimes arise for the investigation of particular problems concerned with hours of work, the results of which, whilst throwing little light on the effects of the actual number of hours worked, yet lead to conclusions of practical relevance in other respects. The following report contains two short studies of this kind.

In the first of these the suitability of an unbroken five-hour spell for women is discussed, and the conclusion is reached that the introduction of short rest pauses about the middle of the spell has many advantages, and that various ways exist in which the difficulties experienced in certain processes may be successfully surmounted.

The second study is devoted to exploring the effects on rate of output, loss of working time, absenteeism, sickness and labour turnover, of the double-shift system for women (*i.e.* the system under which women and girls over sixteen may under prescribed conditions be employed between 6 a.m. and 10 p.m. in two shifts not exceeding 8 hours each) as compared with a single day shift of 8 a.m. to 5 p.m.

The investigation was necessarily limited to the few factories where suitable data were available, and the conclusions reached must accordingly be regarded as tentative. It fails, generally speaking, to disclose any noticeable advantages from the point of view of fatigue and efficiency in favour of the one or the other system, and in fact the only positive result obtained is the suggestion of an unconscious distaste for a change of system, whether from day work to shift work or *vice versa*.

It should be added that inasmuch as the double-shift system is mainly intended to be an alternative to ordinary overtime, a more appropriate comparison would have been between the shift system and days on which the ordinary hours were extended. No facilities for this, however, were found to be available.

February, 1928.

(28937) Wt. 13590/533/877 1000 3/28 Harrow G. 25.

A STUDY OF FIVE-HOUR WORK SPELLS FOR WOMEN, WITH REFERENCE TO REST PAUSES.

By H. M. VERNON, M.D AND M. D. VERNON, M.A.
Investigators to the Board.
Assisted by ISABEL LORRAIN-SMITH, M.A.

CONTENTS.

INTRODUCTION.

The hours of labour of a very large proportion of the factory workers in this country are 47 or 48 per week, and as it is customary for them to work only 4 hours on Saturday mornings, it follows that about 8¾ hours must be worked on the other five days of the week. Such hours are split up into two periods, one of which is frequently 4¾ or 5 hours in duration, and in some factories (as for instance those in which the operatives take their meals at different times) a 4¾ or 5-hour spell is difficult to avoid. Again, if Saturday work is discarded altogether, as is becoming increasingly common, then a 47½-hour week necessitates a 9½-hour day, and 5 or 4¾-hour work spells become the natural practice.

It has been proposed that if any work spell lasts more than 4½ hours and not longer than 5 hours, all women and young persons (i.e. girls and boys under 18) must be given a break of 15 minutes' duration during the spell. Though the introduction of short breaks during the work spells has become increasingly

common since the war, they are not by any means in universal favour. Hence it is desirable to ascertain, so far as is possible, the advantages and disadvantages of a compulsory break As will be gathered from what follows, it is extremely difficult to obtain clear-cut evidence on many of the points at issue, but nevertheless, we consider that we have obtained enough to warrant us in coming to a definite conclusion on the critical question of compulsion.

THE ADVANTAGES OF A BREAK IN FIVE-HOUR WORK SPELLS.

It will be convenient to consider first of all the advantages of introducing a short break during the work spell. Such advantages may be grouped under the headings of (*a*) physiological and (*b*) psychological, whilst their effects are shown by their influence on the efficiency and the health of the workers.

(*a*) *Physiological Advantages.*

The physiological advantages of a break depend chiefly on nutrition. If the work spells last 5 hours the workers have to go for 5½ or 6 hours, and occasionally even longer, without any food, for they necessarily take some minutes to get from their homes to the factory. We collected detailed information on the times of transit at four factories, and we have recorded it in statistical form in Table I. Factories A and C are situated on

TABLE I.—*Time taken by workers to get from home to factory.*

Minutes taken.	Percentage of Workers taking various times at			
	Factory A.	Factory C.	Factory E.	Factory F.
Less than 15 minutes	7	15	3	77
15–29 minutes	4	29	26	23
30–44 ,, ...	24	40	32	—
45–59 ,, ...	34	11	34	—
60–74 ,, ...	31	4	5	—
75–115 ,, ...	—	1	—	—
Median time in minutes	52	32	40	10
Numbers of workers investigated ..	235	586	1,821	40

the outskirts of London, and many of the workers lived at a distance and had to come by train, bus or bicycle. We were able to ascertain the localities of their homes, and the transport facilities; and we calculated that whilst, at one factory, the median (or middlemost) time taken by the workers was 52 minutes, it was only 32 minutes at the other factory. A fair number of

women took well over an hour to come to work, and it must be remembered that such of them as came by train or bus would have to allow a margin of a few minutes in case of unexpected delays. The majority of the workers got their dinner at the works canteen, where they were served with very slight delay; but we may say that, on an average, nearly 6 hours must have elapsed between breakfast and dinner. Factory E was situated about three miles outside a large town, and though the employers did a great deal to assist transport, the median time taken to get to the works was 40 minutes The small number of data collected at Factory F, which was in the centre of a town, indicated only a very brief time for transit.

So much do the workers feel the need for refreshment in the course of the long morning work spells that in our experience, if they are not given official permission by the management, a very large proportion of them nibble food surreptitiously at odd times unless strictly forbidden to do so. As a rule the management turn a blind eye to the custom, because they realise that it makes for increased contentment.

The physiological effect of the rest-pause, though mainly related to the relief of hunger, also affords some relief to physical fatigue, and gives an interval for recuperation. Though direct statistical evidence is lacking, there is a widely held impression that a cup of tea acts as a powerful but harmless stimulant to flagging energies. One large firm visited by us are so convinced of its efficacy that they offer a free cup of tea or cocoa to every worker in the morning and afternoon work spells, and during the dinner hour.

(*b*) *Psychological Advantages.*

The psychological effects of a rest-pause may be even greater than the physiological, especially for operatives engaged on monotonous repetition work. As May Smith (1922) suggests, "We can face with equanimity, and even with enthusiasm, a period of two hours' work with the prospect of a rest, but to look forward to four or five hours' work unbroken is likely to damp the enthusiasm of even an ardent worker." Almost all the workers appreciate a brief rest, even if they are on a piece-rate and thereby lose working time, whilst most of the employers who have introduced rests experimentally have retained them. In workrooms filled with noisy machinery the rest-pause is especially welcome, provided that the machinery is stopped, because it gives an opportunity for conversation.

It is impossible to measure the psychological effect of a rest-pause directly, but indirect evidence was obtained from a study of the labour turnover at three factories where somewhat similar work was performed at similar rates of pay. All the factories were large, well-constructed and well-appointed modern buildings, and were situated in London or on its outskirts. The weekly hours of work were nearly the same, and yet we see from Table II

TABLE II.—*Labour Turnover.*

Factory.	Number of Workers.	Occupation.	Weekly Hours of Work.	Work Spells in Hours.	Rest Pauses in Minutes.	Percentage of Workers leaving in: 1923. Voluntary.	1923. Involuntary.	1924. Voluntary.	1924. Involuntary.	1925. Voluntary.	1925. Involuntary.	Total per Annum.	
B	970	Making biscuits and confectionery.	48	4½, 4½	15, 15	12	12	12	15	11	1	21	25
	158	Baking biscuits ..	47¾	4½, 4¼	15, 15	23	13	22	5	24	1	29	
A	624	Making confectionery and cocoa.	46½	4, 4½	3, 3	29	17	35	15	34	27	52	42
	229	Packing tea	46½	5, 3½	3, 3	—	—	—	—	28	4	32	
C	529	Making chocolates and cocoa.	47½	5, 4½	0, 0	89		81		111		94	

that whilst, at Factory B, the labour turnover during the years 1923 to 1925 averaged 25 per cent. on the average number of women employed, it averaged 42 per cent. at Factory A, and 94 per cent. at Factory C. If we consider only the groups of women engaged on the more closely comparable occupations of manufacturing confectionery (together with biscuits or cocoa), we find an even more striking difference, for the labour turnover at the Factories B, A and C averaged 21, 52 and 94 per cent. respectively. Labour turnover depends on such a number of different factors that it is impossible to argue closely, but it is a suggestive fact that at the factory with the lowest labour turnover the workers were given a 15-minute rest-pause in each work spell, during which they went to the canteen, and a free tea was provided for them in the afternoon. In the factory with the intermediate turnover the workers did not leave their places, but had a three-minute pause in which to drink the tea provided by the management, whilst in the factory with the highest turnover no rests at all were allowed, and the workers were discouraged from surreptitious feeding. Moreover, since they were on a five-day working week they had to put in work spells of 5 and $4\frac{1}{2}$ hours daily for half the year, though the morning spells were reduced to $4\frac{1}{2}$ hours in the remaining half.

It will be noted that in Table II the labour turnover is distinguished as voluntary, or due to the wish of the employees, and involuntary. or due to the wish of the employer. A good deal of the involuntary turnover was the result of unavoidable seasonal variations in trade ; but if the voluntary turnover at factories B and A is compared, it will be seen that it differs even more widely than the total turnover. We were unable to obtain separate figures for voluntary and involuntary turnover at Factory C. The turnover figures quoted for this factory relate only to the last six months of 1923 and the first three months of 1925, but to the whole of 1924.

(c) *The Influences of Rest-pauses on Output.*

If the physiological and psychological effects of rest-pauses are at all substantial, they are bound to reveal themselves in an improved efficiency of the workers. If their output remains steady it means that their rate of production has been accelerated sufficiently to compensate for the loss of time incurred by the rests, and if their output improves the rate of production must have been still more accelerated. We were unable to obtain any evidence concerning the effects of introducing a rest-pause during 5-hour work spells, but the considerable volume of evidence collected previously by the Board's investigators in relation to shorter work spells can be directly applied to the longer ones. Thus, a 10-minute rest taken during the course of a 4-hour spell represents a loss of 4·2 per cent. of working time, and if it produces a favourable effect on output how much more

efficacious should a similar rest be if taken in the more wearisome 5-hour spell, where it represents a loss of only 3·3 per cent. of working time.

The evidence in question is tabulated in Table III.

TABLE III.—*The Influence of Rest-pauses on Output.*

Reference Number.	Occupation.	Duration of Work Spells in Hours.	Rest Pauses Introduced.	Percentage Alteration of Output.	
1	17 girls labelling	$4\frac{1}{2}$, $4\frac{1}{2}$	10 min. in morning	+13	+6.2% (after some months.)
2	6 girls pressing cardboard	$4\frac{1}{2}$, $4\frac{1}{2}$	10 ,, ,,	+5	
3	13 girls tying small packages	$4\frac{1}{2}$, $4\frac{1}{2}$	10 ,, ,,	+8	
4	5 women closing (boots and shoes).	$4\frac{3}{4}$, $4\frac{1}{2}$	10 ,, ,,	+11	
5	7 girls assembling bicycle chains	$4\frac{5}{6}$, $3\frac{3}{4}$	5 min. per hour..	+13	
6	6 girls folding handkerchiefs.	$4\frac{1}{2}$, $4\frac{1}{2}$	7 min. in morning	+4·4	
7	6 girls working calenders	$4\frac{1}{2}$, $4\frac{1}{2}$	7 ,, ,,	+4·0	
8	8 women ironing ..	$4\frac{1}{2}$, $4\frac{1}{2}$	7 ,, ,,	+0·4	
9	29 women hemstitching handkerchiefs.	$4\frac{1}{2}$, $4\frac{1}{2}$	7 ,, ,,	−3·4	
10	8 girls folding handkerchiefs.	$4\frac{1}{2}$, $4\frac{1}{4}$	10 min. in morning	+2·3	+2.8% (immediate effect)
11	4 women ironing ..	$4\frac{1}{2}$, $4\frac{1}{4}$	10 ,, ,,	+1·6	
12	4 girls stamping out tin discs.	5, 4	10 min. in each spell	+0·7	
13	1 girl polishing spoons ..	4, 4	5 min. per hour..	+3·7	
14	5 women on light work..	$4\frac{1}{2}$, 4	7 min. in each spell	+5·5	

The first nine sets of observations were made by Vernon and Bedford (1924), and, except in one instance, they show the effect of introducing a 10 or 7-minute rest pause in the middle of the morning work spell, when $4\frac{1}{2}$ or $4\frac{3}{4}$ hours were being worked. In the exceptional case a 5-minute rest was taken each hour of both spells. It will be seen that the output improved in every instance but one, the average improvement being 6·2 per cent. The observations numbered 10 to 12 were made by Wyatt and Fraser (1925), whilst No. 13 was made by Farmer and Brooke (1921), and No. 14 by Farmer and Bevington (1922). These five sets of observations showed an average improvement of output amounting to 2·8 per cent., or less than half as much as before. The reason of this reduced effect is that the output was compared immediately before and after the introduction of the rests, whilst in the other series a period of several months was allowed to elapse before the output was estimated. As was shown by Vernon and Bedford, the full effect of the rests is attained only gradually. This is due to the fact that the workers unconsciously accelerate their speed of production in consequence of their increased vigour.

It can be gathered from Table III that all the occupations investigated consisted of light repetition work. Half of them involved purely manual operations, and in all but one of them there was a good deal of hand work. The single occupation which showed a reduction of output consisted of hem-stitching, and this is largely a machine operation which cannot be accelerated. Certain machine-tending operations give the operators practically no chance of accelerating their rate of production, so that in their case the introduction of a rest-pause may mean a loss of output directly proportional to the loss of productive time. Such occupations are the exception, and it is probable that in the great majority of cases the introduction of a rest-pause will mean a gain of productivity.

(*d*) *The Influence of Five-Hour Work Spells on the Health of the Workers.*

If unbroken 5-hour work spells throw a definitely greater strain upon the workers than that entailed by shorter spells, it follows that their health may be affected, and their sickness rate increase. The effect is not likely to be a large one, and whether it exists or not it is extremely difficult to obtain reliable information about it, owing to the innumerable other factors upon which sickness depends. For instance, the sickness rate is greatly influenced by epidemics of influenza, colds, and other infectious diseases, so that quite apart from the usual seasonal variations, it may vary considerably from year to year, and a rise or fall in successive statistical periods, when 5 or $4\frac{1}{2}$-hour spells are worked, would not necessarily be due to the change in the length of spell. The best evidence we were able to obtain avoided this particular difficulty, because it related to two groups of women at the same factory who worked different lengths of spell. The group of women, 620 in number, who were engaged in making chocolates (chiefly by hand dipping), toffee, and cocoa, had their dinner hour from 12 to 1, and worked for spells of 4 and $4\frac{1}{2}$ hours respectively, whilst the other group, numbering 229, who were employed on tea-packing, had their dinner hour from 1 to 2, and worked for spells of 5 and $3\frac{1}{2}$ hours respectively.

As can be gathered from Table IV, the sickness rate of these latter women during 1925 was distinctly greater than that of the former group, but their loss of time from voluntary absenteeism was less, so that the total time lost was the same. As the sickness rate is often considerably influenced by the inclusion of a few chronic cases, we worked out our data in two ways, firstly with the inclusion of all the sickness, and secondly with its inclusion only for the first 30 days. It will be seen from the Table that even with this correction the sickness of the tea packers was still distinctly greater than that of the confectionery workers. How far it was due to the longer work spells it is impossible to say, for there were a number of other variables in the conditions under

TABLE IV.—*Sickness in Relation to Length of Work Spells.*

Occupation.		No. of Workers.	Duration of Period investigated in Months.	Weekly Hours of Work.	Work Spells in Hours.	Rest Pauses in Minutes.	Per cent. Time lost from			Per cent. Time lost (excluding absences over one month).		
							Sickness.	Other Causes.	Total.	Sickness.	Other Causes.	Total.
Factory A	Making confectionery and cocoa.	620	12 (1925)	46½	4, 4½	3, 3	2·4	1·3	3·7	2·2	1·2	3·4
	Packing tea	229	12 (1925)	46½	5, 3½	3, 3	3·2	0·5	3·7	2·7	0·4	3·1
Apparent effect of long work spell..		—	—	—	—	—	+0·8	—0·8	0	+0·5	—0·8	—0·3
Factory D	Repairing telephones (winter).	142	6 (1925–26)	48	4½, 4¼	0, 0	(3·4)	—	—	(2·7)	—	—
	Repairing telephones (summer).	155	6 (1926)	48	5, 3¾	0, 0	(3·9)	—	—	(1·9)	—	—
Apparent effect of long work spell..		—	—	—	—	—	+0·5	—	—	—0·8	—	—

which the two groups of women worked, besides that of different work spells. Perhaps the most important difference lay in the posture of the women, for the tea packers stood all day at their machines, whilst the majority of confectionery workers were sitting.

Another attempt to obtain evidence was made at a telephone repair factory, where the women worked for spells of $4\frac{1}{2}$ and $4\frac{1}{4}$ hours in the winter months (October to March), and for 5 and $3\frac{3}{4}$ hours in the summer months (April to September). In addition to any influence of work spells, there must necessarily have been a considerable seasonal variation in the sickness. This we have corrected for on the basis of the results obtained in 1925 with the groups of tea packers and of confectionery workers at Factory A, and of those obtained in 1923 to 1925 with the groups of confectionery workers and of biscuit bakers at Factory B. In these four groups the winter and the summer sickness was 17, 18, 16 and 13 per cent above and below the respective means, or 16 per cent. on an average. It will be seen from Table IV that the corrected figures show that if the total sickness is considered there was an excess in the summer months when 5-hour spells were worked; but if the chronic cases of sickness are excluded, there was less sickness in the summer months. In any case it is evident that no great reliance can be placed on this result. It is recorded, like the previous set of observations, mainly with the idea of indicating the practical impossibility of obtaining really reliable evidence as to the influence of a moderate change in the duration of work spells on the sickness rate. The loss of time from sickness at the two factories averaged 3·2 per cent., and probably this represents a fair average standard of health. We collected sickness data relating to groups of 120 to 809 women, over periods of 5 to 36 months, at ten factories where boots and shoes, tin canisters, war munitions, polishes, and other articles were manufactured, and we found sickness rates varying from 1·9 to 4·5 per cent., with an average figure of 3·2 per cent., i.e. the same as that of the two factories cited. The hours of work of the factories ranged from 43 to 48 per week.

The Disadvantages of a Break in Five-Hour Work Spells.

In order to obtain the views of employers about the disadvantages—and advantages—of 5-hour work spells, we visited factories in a number of industrial centres, including London, Birmingham, Derby, Nottingham, Leicester, Kettering, Liverpool, Manchester, Edinburgh, and Glasgow, and altogether we investigated 42 factories where 5-hour work spells were in force. In 13 of these the employers stated that they would have no objection to the introduction of a compulsory break, whilst in 13 of them they did not object to the principle of a break, provided that the employees were allowed to take it at different times, convenient to the management. In the remaining 16 factories

the employers objected to any kind of break. One of the reasons most frequently advanced against it was that where men and women are working in conjunction on machines such as printing presses, the granting of a break to the women would mean the stoppage of the machinery, and the temporary idleness of the highly paid skilled men. In the larger printing works, where there were a number of presses, it was admitted that it would be possible to replace temporarily the one or two girls attached to a machine by those belonging to another which happened to be idle, but in small works with only a few machines this would be more difficult. Even there, however, there are often one or two extra women available who could act as substitutes. At some factories (e.g. biscuit-baking, chocolate-moulding) where a rest-pause was in force, the practice of allowing girls on various machines to have their rest in relays, and to replace them temporarily by girls drawn from other sources, was carried out systematically and without difficulty.

Another objection was the purely economic one that a break meant a loss of working time, and therefore a decrease of productivity. Some employers were so convinced of the validity of this argument that they said that the time taken for the compulsory rest would have to be added on to the end of the working day. Other employers demurred to the waste of power produced by taking women off machines run by the same shafting as other machines on which men were employed.

The most substantial objection raised related to the loss of extra working time over and above that of the nominal 10 or 15-minute break. In certain instances, which are discussed below, this extra time was due to the difficulty in restarting the complicated machinery employed in certain continuous or semi-continuous processes, but apart from that some employers considered that the break interrupted the swing of the work, and caused the women to waste some little time in settling down to work again after it was over. In one large biscuit factory investigated by us this waste of extra time was particularly manifest amongst certain of the operatives. For instance, the girls employed in coating biscuits with chocolate usually stopped work 4 minutes before the break in order to wash their hands They proceeded to the canteen and did not return to work for 16 to 20 minutes instead of the nominal 15 minutes. There was a further delay in getting the machines started, so that they were idle for an average period of 26 minutes When the employees are allowed to go to a canteen during their break, it is often troublesome to get them to return promptly, and sometimes this is due to the difficulty of supplying a considerable number of workers with tea and food at the same time. Still, it is a question of discipline, and in a number of cases investigated by us the nominal duration of the rest-pause was rigidly kept to. If tea is offered to the women from an urn which is brought to the work-room, it is impossible to supply all of them at the same time, and

those last served are apt to take a few minutes beyond the nominal end of the rest, and this encourages the others to follow suit. The difficulty can be avoided by serving the women in small groups at a time, though this implies that the rest is taken at successive periods, and not simultaneously. The system of tea-drinking which struck us as the best and simplest was for each worker to bring her own tea in a vacuum flask. Thereby all were able to start their meal the moment the siren sounded, and they returned equally promptly to work at the end of their rest.

We made a careful study of the various processes stated by the employers to entail extra delay in restarting, and these we will now discuss *seriatim* :—

Chocolate moulding and demoulding.—In the manufacture of bar chocolate, liquid chocolate is run from a hopper into moulds, and they are transferred to a moving band, under which there is a mechanical shaker, for the removal of air bubbles. At the four factories where the process was investigated by us, the shaking was found to take from 3 to 6 minutes, and the moulds were then carried by another moving band through a refrigerating chamber, so as to solidify the chocolate. The passage through this chamber took 15 to 25 minutes, so there was an interval of 20 to 30 minutes between the filling of the moulds and their arrival at the end of the chamber, where they were " demoulded " by banging them on a bench Once the moulds have reached the refrigerating chamber they can remain there without injury, but the shaking process cannot be interrupted. Hence, if there are no relays available, there must be an extra loss of 3 to 6 minutes of working time when the girls employed on filling the moulds and transferring them to the shaking band are given their rest. If the demoulding girls are given their rest at the same time as the others, it follows that an extra period of 3 to 6 minutes *plus* the time of the rest taken by the moulding girls will be wasted by them shortly after their return, when the gap in the succession of cooling moulds reaches them. But if the time taken by the moulds to pass through the refrigerating chamber is known and allowed for, there need be no extra delay. Owing to the expense entailed by shutting down the elaborate machinery, one of the firms visited by us did not stop it even during the dinner hour, but put on a relay of fresh girls so as to make the process continuous. They could, of course, equally well put on relays during a rest-pause, provided that all the women did not have to take their rest at the same time.

Chocolate enrobing.—The sweet " centres " of chocolate are frequently coated with a layer of chocolate by means of " enrobing " machines, and we investigated the process at five factories where these machines were installed. Usually the centres are arranged by hand on a moving band which slowly carries them forward to a moving chocolate-coated wire band. Here they become coated with chocolate underneath, and a third band carries them

on to the enrobing machine proper, where a stream of liquid chocolate passes over them. Another moving band takes them on to the cooling chamber, but before this is reached they are usually marked by hand with streaks or other patterns. The centres, once started on their journey, usually take 5 minutes in reaching the cooling chamber, and 7 to 10 minutes to pass through it. At one factory we were told that in order to obtain the highest quality of chocolate, the centres ought not to be interrupted in their passage until they have reached the cooling chamber, so there would be about 5 minutes extra loss of time if all the four girls usually employed for the pre-cooling stages on each machine were given their rest at the same time, whilst if the girl at the far end of the cooling chamber was likewise included the loss of time would amount to 12 or 15 minutes If, however, the girls engaged in putting the centres on the band, those engaged in marking them after the enrobing, and those who collected them after their passage through the cooling chamber, were allowed to take their rest at slightly different times, the loss of extra time involved would be only two or three minutes. In fact, this method of taking rests at the times best calculated to eliminate extra delays was systematically adopted in various processes of chocolate manufacture at two of the factories visited by us. At some of the other factories, where possibly they did not aim at such a high quality of manufacture, they told us that they could stop the process at any time without detriment. Even in the factory which specially deprecated any stoppage there were two or three brief stoppages per hour (usually lasting one to three minutes each but sometimes longer) owing to slight mechanical breakdowns, and these appeared to do no harm.

Chocolate dipping.—With hand-made chocolates the sweet centres are dipped individually in a pool of liquid chocolate, which is spread on the top of a table or contained in large oval basins. The chocolate is kept warm in the centre and cool at the edges, and when the girls start on their work after the dinner hour it takes them 10 minutes, on an average, to work it up to the right consistency and temperature for dipping. The management at one factory maintained that if the girls were given a 15-minute rest they would waste a good deal of extra time in getting the chocolate to the right consistency, but at another factory we observed that they took only one minute for this purpose on returning from a 15-minute rest. At a third factory they took practically no time in restarting after they had had a 10-minute rest, but the management thought that they would have needed 5 minutes for the purpose if the rest had been prolonged to 15 minutes. Again, the management at the first factory deprecated the loss of chocolate entailed by the washing of hands before a break, but we observed that even without a break the majority of the girls left their tables at some time or other during the spell. They were absent for 7 minutes each, on an average, and in nearly all cases they washed their hands.

The other firms did not attach much importance to hand-washing, for the girls avoided all but a slight waste by scraping off the chocolate previous to leaving their tables, and then cleaning with a rag, from which the cocoa fat was subsequently extracted.

Biscuit baking.—In the operation of biscuit baking the dough is first cut up into small pieces in machines frequently tended by women. The machine arranges the biscuits upon trays which are then placed upon a moving band and carried through a long oven. They usually take 5 to 12 minutes in the passage, but exceptionally the time varies from 4 to 30 minutes, and the journey cannot be interrupted. Usually the loading and unloading of the trays is done by men, but in one very large factory visited by us women were employed. If all the women tending the cutting-up machines and loading and unloading the ovens had been given a rest at the same time it would have meant a serious loss of production. But it was possible to withdraw a small number of women from each operation without holding up the process, and the workers were allowed to go away, a few at a time, for a 15-minute rest in each work spell without creating any stoppage at all

Other processes.—We studied several other processes in which it was sometimes maintained that extra time would be lost in starting up after a break, but we did not find the claims to be substantial. In *french polishing*, for instance, the article is rubbed over with varnish, and with certain qualities of varnish it is necessary to complete the coating before a stop. Hence in this occupation there might be a little loss of extra time in stopping work before the break was due, but it would be very small, and if the rest were taken at such a time as was convenient to the management, there would be no loss at all. However, some loss of extra time is apt to be caused by the difficulty of cleaning the hands It is best to remove the varnish from them by means of warm spirit, but it is expensive to provide this for each rest-pause taken, as well as at the end of the two work spells. At one factory the girls did not trouble to wash their hands before eating food.

In *tea-packing* the packets are filled by means of elaborate machines, and we were told that there would be a loss of extra time in restarting. However, we found that at a large factory with over fifty packing machines, all of them were running within three minutes of the women's return to their afternoon work spell. Again, the machines had to be stopped once or twice an hour for re-adjustment, and the time lost over restarting after each stoppage was found to average only 1·4 minutes.

In *jam manufacture* the cooked jam is run into tins and wooden troughs where it is stirred up until it has reached the right temperature for pouring into the jars. We were told that it would be difficult to give the employees a rest at a fixed time, because it

might happen to fall just when the jars were being filled, but it would be quite easy to give them a rest at such a time as was convenient to the management.

In the other occupations studied by us, among which were letterpress printing, lithographing, bookbinding, telephone repairing, laundry work, the manufacture of hosiery, woollen goods, clothing, waterproofs, cloth caps, boots and shoes, mattresses, pins, jewellery, tin canisters, polishes, etc., there appeared to be no difficulty in stopping and starting up the work again at a moment's notice ; so we may say that, as the result of a fairly wide experience, the number of occupations in which a compulsory stoppage would cause a definite increase of non-working time over and above that entailed by the rest, is very small. We see that even when a loss does occur it is usually of small dimensions, and when it is substantial it can be avoided by the employment of temporary substitutes or of relays. It should be pointed out, however, that the introduction of a 10 or 15-minute break at factories where it has been customary to give a number of short breaks during the work spells is difficult. We visited one factory which had work spells of $4\frac{3}{4}$ and $3\frac{1}{2}$ hours, and in one operation, which was particularly monotonous in character, a 5-minute break was given in every hour. It is clear that the total length of time taken in breaks was adequate ; and for this type of work numerous short pauses were probably more restful and stimulating than a longer continuous break.

A good many of the employers who objected to the idea of a compulsory break told us that they would avoid it by reverting to $4\frac{1}{2}$-hour work spells. Even in factories where lack of canteen accommodation necessitates the adoption of two different dinner hours it would generally be possible to fit in $4\frac{1}{2}$-hour spells. In the instance quoted previously, half the girls could have started work at 7.30 a.m. and have had their dinner hour from 11.30 to 12.30, whilst the other half could have started work at 8 a.m., and have had dinner from 12.30 to 1.30.

General Conclusions.

The general conclusion arrived at is that the introduction of a compulsory rest at a convenient point in 5-hour work spells has many advantages and few disadvantages, though it would not always be possible in the case of continuous or semi-continuous processes to give such a rest to the whole of the workers simultaneously. In order that the rest-pause should be efficacious, it should be given at a time fairly near the middle of the work spell. At one factory we found that some of the women were required to take their rest-pause at 9 a.m., or only an hour after they had come on to work. The reason assigned was that most of them had taken nearly an hour to reach the factory, so that they were getting their rest and refreshment two hours after their early breakfast Probably it would be best to arrange that the rest should not be taken

sooner than $1\frac{1}{2}$ hours after work had begun, and not later than $1\frac{1}{2}$ hours before the end of the work spell, i.e. it would have to be taken in the middle 2 hours of the 5-hour spell (*cf.* Wyatt, 1927).

The most suitable duration of the proposed rest-pause is not easy to decide; but most proposals favour an interval of 10 or 15 minutes. We are inclined to favour the shorter interval, for in the first place the nominal time is usually exceeded, so that a nominal 10 minutes means an actual 15 minutes, whilst a nominal 15 means an actual 20 minutes Then "a quarter of an hour" sounds so substantial a period that employers are very likely to reckon it as a loss of productive time which must be made up for by adding on an extra quarter hour of working time at the end of the day. "Ten minutes," however, is usually not reckoned as a loss of working time which requires compensation. Another objection, which may in some instances be a substantial one, relates to the loss of manual dexterity during the rest. Every skilled or semi-skilled worker, when first she starts on her daily task, takes some minutes to "warm up" to her maximum productive capacity, and to acquire her usual manual dexterity, whilst she begins to lose some of this dexterity directly she stops work. There is some reason for thinking that in a 15-minute rest there is, at least in some occupations, a distinctly greater loss of dexterity than in a 10-minute rest. Evidence upon this point is difficult to obtain, but one set of appropriate data which came to our notice is suggestive, even if not conclusive.

The work in question related to women employed in engraving clinical thermometers. The instruments were dealt with in bundles of 72, and all of them were first coated with wax, and then they were all engraved, etched, and unwaxed. Finally the etched design was filled in with black paint, and the instruments were cleaned and polished. The whole sequence of operations took about 50 minutes. Four skilled women were tested over a 7-hour day, and they were allowed to work :—

(*a*) without any rest periods other than the usual dinner hour;

(*b*) with a rest-pause of 30 minutes between the completion of each two batches of instruments;

(*c*) with a rest-pause of 15 minutes after the completion of each batch.

As the result of observations extending over six to eight days in each instance, it was found that under scheme (*a*) the average time taken per batch was 49 minutes; under scheme (*b*) it was 51 minutes, and under scheme (*c*) 52 minutes. Hence the rests, so far from increasing efficiency, appeared to induce an actual loss of manual dexterity. It should be realised, however, that, owing to the considerable variety in the succession of operations required, a prolonged rest from each individual operation was automatically obtained. It is very seldom that ordinary industrial occupations afford so much variety, spread over such a lengthy interval of time.

The reality of the temporarily acquired dexterity in the thermometer engraving is proved by the fact that the women working under scheme (*a*) took 12 per cent. more time than their average over the first batch of thermometers engraved in the morning, whilst they took 6 per cent. more time over the first set engraved after the dinner hour.

SUMMARY.

The adoption of a rest-pause—with opportunity for refreshment—during work spells of 5 hours' duration is desirable :—

(*a*) for physiological reasons, dependent on the fact that there is often a period of 6 hours between breakfast and dinner ;

(*b*) for psychological reasons, dependent on the relief from monotony.

The rest-pause increases the efficiency of the workers, for in various occupations (with 4½-hour work spells) the immediate effect of introducing a rest was to increase output by 2·8 per cent., whilst the improvement in other groups of workers who were tested some months after the introduction of the rest amounted to 6·2 per cent. Also the introduction of a rest appeared to reduce the labour turnover greatly.

A compulsory rest-pause is disadvantageous to output in a small number of semi-continuous occupations connected with the manufacture of chocolates and biscuits, because it involves the waste of a good deal more time than that of the nominal rest-pause. However, this objection can be avoided by employing temporary substitutes, and by arranging that various groups of women take their rest-pause successively, and not simultaneously. This principle can be advantageously applied to many other occupations.

For various reasons it is probable that a 10-minute rest-pause is better than one of 15 minutes.

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A STUDY OF THE TWO-SHIFT SYSTEM IN CERTAIN FACTORIES.

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CONTENTS.

I. Introduction.

Under Section 2 of the Employment of Women, Young Persons and Children Act, 1920, the employment of women and young persons over 16 years of age on two shifts of not more than eight hours each between the hours of 6 a.m. and 10 p.m. from Monday to Friday, and 6 a m. and 2 p.m. on Saturday may be allowed by permit from the Home Office on the joint application of the employer and the majority of the workers concerned. Certain special conditions, chiefly relating to welfare, are attached to the granting of permits. An account of these conditions is given in the report of the Chief Inspector of Factories for 1924,* together with a general survey of the working of the system for the preceding four years. In the following report an attempt is made to study in detail the working of the system in a small number of factories.

Representations were made by employers in several trades to the Departmental Committee on the Employment of Women and Young Persons on the Two-shift System† as to the importance to them of this permission. About five hundred Orders, or permits, were issued up to the end of 1925 ‡ In the course of this investigation, however, only a small number of factories, not more than fifty, was discovered where more than eight or ten women or young persons were employed fairly regularly on the shift system during the years 1925 and 1926; though there were no doubt others where the system was worked for short periods of time during those years. These factories employed

* Annual Report of the Chief Inspector of Factories and Workshops for the year 1924. p. 49–55.

† Report on Employment of Women and Young Persons on the Two-Shift System. Cd. 1037, November, 1920.

‡ Annual Report of the Chief Inspector of Factories and Workshops for the year 1924. p. 50. Report for the year 1925. p. 7.

altogether not more than four thousand persons. At one firm about two thousand women and young persons were on shift work, at two firms there were two or three hundred, and at two firms about one hundred. The remainder had less than one hundred workers on shifts. More than half the four thousand workers were drawn from the North Midlands district.

Below is given a table (Table I) of the number of factories visited in various districts, together with the trades carried on and the number of workers on shifts at those works in which a detailed investigation was undertaken. Wherever possible, statistical data dealing with output, lost time, sickness, etc., were obtained. Some information of a sociological nature dealing with hours of sleep, meals, housework, etc., was collected by means of a formal questionnaire.* Among those factories visited in which the shift system was still in operation, or had only recently been given up, only a small number were suitable for such detailed investigation, or possessed records containing useful data. But in a variety of other factories similar questions were put to some of the workers, and the opinions of managers, foremen, welfare workers and trained nurses were obtained whenever possible.

TABLE I.—*Details relating to Factories Visited.*

District.	No of Factories visited.	Factories where detailed information was obtained.		
		Reference Letter.	Trade or Occupation.	No. on Shifts.
London ..	18	H	Manufacture of Margarine ..	60
South Western (including Wales).	1	—	——	—
South Midlands	5	C	Printers and Paper Bag Manufacturers.	60
		F	General Engineers, manufacturing small metal parts.	60
		E†	Electrical Engineers, Telephone Manufacturers.	90
North Midlands	5	A	Artificial Silk and Hosiery Manufacturers.	2,000
Lancashire ..	5	B	Electrical Engineers	100
		G	Telephone Cable Manufacturers	20
Yorkshire ..	7	D	Wire Manufacturers	50
Northern ..	4	—	——	—
Total ..	45	—	——	2,440

* The questions were given orally to one worker at a time, and the answers written down immediately. This procedure was thought likely to give more accurate results than a written questionnaire. The average factory worker is not accustomed to written examinations, moreover, the latter give more time for invention and the exercise of the imagination in answering.

† Shift system recently given up.

It is proposed to consider the effects of the system in detail; (*a*) as they were directly manifested in the factory itself in connection with output, loss of working time, etc., (*b*) as they appeared more indirectly in connection with sickness, absenteeism and labour turnover.

II. Output and Loss of Working Time.

Output.

It is of interest to the employer to know how the output will be affected by a change from ordinary day-work to shift-work. It has been possible to obtain such data from five firms, and they are given in Table II.

TABLE II.—*Comparison of Output on Day Work and Shift Work.*

Factory	Number of Workers	Relative Output per hour (per cent of Mean)				Hours of Labour.		Relative Output per week.	
		Shift Workers	Day Workers	Difference	p e of Difference	Shift Workers	Day Workers	Shift Workers	Day Workers
		%	%	%				%	%
B	39 Coil Winders (I) .	101	97	4	0 62	40¾	47	95	105
B	7 Coil Winders (Ia) .	102	95	7	1 12	40½	47	97	103
D	18–30 Wire Drawers	99	101	−2	3 19	43½	47	95	105
E	30 Coil Winders (II)	100	100	0	—	40¾	47	93	107
E	6 Engravers	104	97	7	1 99	40¾	47	96	104
F	5 Lathe Workers (I)	111	90	21	2 34	41¼	49	102	98
							55	96	104
F	9 Lathe Workers (II) .	109	92	17	1·99	41¼	49	100	100
							55	94	106
G	10 Cable Workers (I) .	115	85	30	3 48	41¼	49	106	94
G	10 Cable Workers (II)	111	89	22	3·64	41¼	49	102	98
	Average	106	94	12	—	41	49	98	102

It will be observed that in most cases the number of workers whose output was measured was small. This was unavoidable; but all the data, however, extended over a period of not less than three months on day-work and three months on shift-work

The coil winders from Factory B and Factory E were engaged on winding wire on wireless accumulator coils. The work was only semi-automatic, and required considerable skill in guiding the wire. Coil winders (Ia) comprised a small group selected from coil winders (I) because the former were employed continuously throughout the experimental period on winding the same type of coil. The wire drawers were engaged in drawing out wire from a thick gauge to a thin; the wire was dragged by revolving rollers through a series of narrowing holes. The work of setting up the wire was arduous; but there were considerable periods of rest while it was running smoothly The engravers were engraving vulcanite plates with metal styles. The lathe workers at Factory F were engaged on turning and grinding large nuts, screws, etc., on hand-operated machines; the work appeared to be very heavy. The cable workers were tending the machines which wound insulating paper round the wire cables, and joining the paper when it broke; this work was neither heavy nor difficult.

All these groups, with the exception of the lathe workers (I) from Factory F, were originally on day-work and then changed over to shift-work or vice-versa. But lathe workers (I) comprised two parallel groups, each of five workers; one group was on day-work, the other on shift-work.

The weekly hours of work given for the shift-workers were the average hours. The hours of work of the morning shift were 43 to 45 and the hours of work of the afternoon shift were only 37½, since this shift did not work at all on Saturday. But the workers almost always changed over from the morning to the afternoon shift once a week; hence it was permissible to average their weekly hours of work. In one or two cases it was found that the shifts only changed over every fortnight or three weeks; but in all the factories for which data are given there was a weekly change-over.

It appears that the output *per hour* was greater on shift-work than on ordinary day-work with two exceptions, coil winders (II) and wire drawers The group of coil winders (II) was only employed on shift-work for three months altogether, and at a very hot time of year; and it is possible that they never became sufficiently used to the change to reach their full output. The output of the wire drawers was very variable, and the measurement of it was subject to many unavoidable irregularities.

When the relative *weekly* output was calculated as a percentage of the mean of the output of both shift-workers and day-workers, it was found that in general this advantage was not maintained and that the output per worker per week was on the average about 4 per cent. lower for shift-workers than for day-workers. That is to say, a decrease in the hours of work produced an increase of hourly output which was not quite sufficient to compensate completely for the shorter hours. Thus an employer who changed from ordinary day-work, with a 48 hour working week, to shift-work, with a total working week of 82 hours, might have expected an increase of output *per machine* of rather over 92 per cent.

TABLE III.—*Comparison of Output of Morning and Afternoon Shifts.*

Factory.	Number of Workers.	Relative Output per hour (per cent. of Mean).				Period of Data.
		Morning Shift.	Afternoon Shift	Difference.	p.c. of Difference.	
		%	%	%		
A	3 Hose Linkers ..	98	104	6	0·92	2 weeks.
H	30–50. Margarine Packers.	97	102	5	0·62	20 months

There is some reason to believe that output was higher on the afternoon shift than on the morning shift. Data from two factories are given in Table III, but not much reliance can be placed on these. In the case of the hose linkers (who sewed up the toes of the hose) the hourly output was measured, and it was found that the output was lowest from 6 a.m. to 11 a.m.

Loss of Working Time.

Output is not infrequently affected by the loss of working time in the factory. This loss may be involuntary on the part of the workers , that is to say, it may be taken up in fetching and carrying material, getting machines adjusted, and so on. Or it may be voluntary , the workers may stop attending to their work in order to talk or rest. In several factories an attempt was made to obtain a comparison of the amount of time lost in these ways by shift-workers and day-workers with the same or a similar type of occupation. Where this was not feasible, the morning and afternoon shifts were compared. Data showing these comparisons are given in Tables IV and V * They relate to small groups of pirn winders and sizing workers, who were engaged on a similar type of work, that is, tending the machines which wound silk from one set of bobbins on to another, and joining up the broken threads The lathe workers at Factory B were turning small metal rods, screws, etc., on light, hand-operated machines. The paper bag makers were tending machines which folded and glued sheets of paper into tea-packets. The galvanizers were tending machines which dragged wire through a bath of molten zinc , this work was heavy and hot while it lasted, but allowed the workers a considerable amount of rest while the machines were running smoothly.

In addition to the data for time lost which might otherwise have been spent at the machine, data are given showing the amount of time during which the workers were able to rest and watch their machines running. This could be done only in certain occupations where the machine merely required to be tended, and had not to be driven or guided. The time spent in this way varied from one to twenty-five minutes per hour : less time was lost voluntarily when these rests could be taken. The average time for shift-workers and day-workers per hour lost voluntarily when work was supposed to be continuous was 6·2 minutes; when the machine allowed time for resting, it was only 3·0 minutes. But this difference was outweighed by the differences between the day and shift-workers. In three cases out of four the

* The figures for time lost voluntarily for the first and last hours of each shift were obtained by neglecting the first and last half-hours of work and doubling the figures for the succeeding and preceding half-hours respectively. It was necessary to do this because of the large amount of time lost in starting or leaving off work during the first and last half-hours of work.

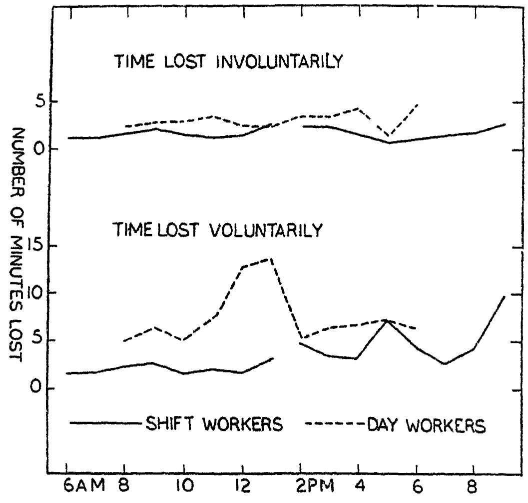
TABLE IV.—*Comparison of Number of Minutes per Hour Lost by Shift-Workers and Day-Workers.*

Factory.	Shift-Workers. Number of Workers.	Time lost involuntarily.	Time lost voluntarily (Machine stopped).	Time spent in resting (Machine running).	Time lost voluntarily and involuntarily.	Day-Workers. Number of Workers.	Time lost involuntarily.	Time lost voluntarily (Machine stopped).	Time spent in resting (Machine running).	Time lost voluntarily and involuntarily.
		mins.	mins.	mins.	mins.		mins.	mins.	mins.	mins.
A	6 Pirn Winders ..	2·2	0·7	1·0	2·9	6 Sizing Workers ..	3·3	3·3	3·2	6·6
A	3 Hose Linkers ..	1·9	2·3	—	4·2	—	—	—	—	—
B	6 Coil Winders ..	1·1	1·9	—	3·0	5 Coil Winders ..	2·1	8·7	—	10·8
B	6 Lathe Workers ..	2·3	9·7	—	12·0	6 Lathe Workers ..	3·9	8·3	—	12·2
D	6 Galvanizers	1·3	2·7	24·6	4·0	6 Wire Drawers ..	5·0	5·2	14·0	10·2
	Average..	1·7	3·5	12·8	5·2	Average	3·6	6·4	8·6	10·0

TABLE V.—*Comparison of Number of Minutes per Hour Lost on Morning and Afternoon Shifts*

Factory.	Number of Workers.	Time lost involuntarily (fetching material, etc.).			Time lost voluntarily (Machine stopped).			Time spent in resting (Machine running).			Difference between 2 Shifts of Time lost voluntarily and involuntarily.
		Morning Shift.	Afternoon Shift.	Difference.	Morning Shift.	Afternoon Shift.	Difference.	Morning Shift.	Afternoon Shift	Difference.	
		mins.	mins	mins.	mins.	mins	mins.	mins.	mins.	mins.	
A	6 Pirn Winders	1·9	2·4	0·5	0·9	0·6	−0· 3	0 9	1·1	0·2	0·2
A	3 Hose Linkers	2·2	1·7	−0·5	1·9	2·6	0· 7	—	—	—	0·2
B	6 Coil Winders	0·9	1·3	0·4	1·5	2·2	0· 7	—	—	—	1·1
B	6 Lathe Workers	2·1	2·6	0·5	6·1	13 2	7· 1 ±0·53	—	—	—	7·6
C	*5 Paper Bag Makers	1·3	0·8	−0·5	0·1	0·2	0· 1	9·5	10·9	1·4	−0·4
D	6 Galvanizers	1·2	1·3	0·1	0·9	4·5	3· 6 ±0 22	26·5	22·7	−3·8	3·7
	Average (excluding C)	1·7	1·9	0·2	2·3	4·6	2·3	13·7	11·9	−1·8	2·5

* The Paper Bag Makers had an unusual system of hours. The first shift worked from 6 30 to 11.30 a.m. and from 1.30 to 3.15 p.m.; the second shift worked from 11.30 a.m. to 1.30 p.m. and from 3.15 to 8 p.m.



Average amount of time lost hourly

day-workers lost considerably more time voluntarily than the shift-workers, the average difference being about 3 minutes per hour. They lost more time involuntarily in every case, the average difference being about 2 minutes per hour. Thus, irrespective of the time allowed for resting by the machines, the shift-workers lost 5 minutes per hour on the average, and the day-workers, 10 minutes. If we assume that the average working week of the shift-workers was 40¼ hours, and the average working week of the day-workers, 46 hours (it varied from 45 to 47 hours), then allowing for the time lost, the net working week of the shift-workers became approximately 37 hours, and of the day-workers, 38¼ hours. Thus in the end the actual time during which the machine was kept running smoothly was nearly as great for the shift-workers as for the day-workers. The difference of time was between 3 per cent. and 4 per cent. It was observed that the calculated average output per week was 4 per cent. lower for the shift-workers than for the day-workers It thus appears that the actual rate of work was almost identical for shift and day-workers. The latter had longer hours but lost more time , so that in the end the net working time per week and the weekly output of the shift-workers were nearly equal to those of the day-workers.

It may be noted from Table V and the Figure that on the average more time was lost during the afternoon than during the morning shift. But only two groups of workers, the lathe workers and the galvanizers, showed a difference large enough to be statistically significant ; and in the case of the latter group this was probably the result of a decrease in the time spent in resting with the machine running. It appears from the hourly curves in Fig. 1 that, neglecting the large increases round about meal-times—9 a.m. and 5 p.m., for the shift-workers, and 12 and 1 p.m., for the day-workers—the amount of time lost voluntarily rose fairly steadily for day-workers and shift-workers throughout the day.

But the average amount of time lost per hour by the shift-workers from 6 to 8 a.m. and from 7 to 10 p.m., when they were alone at work, was no greater than the average amount lost per hour from 8 a.m. to 7 p.m., when the day-workers also were at work. Thus the amount of time lost, either voluntarily or involuntarily, was not increased when the shift-workers only were at work, that is to say when supervision might have been expected to be inadequate, or when the workers might have had to wait for material or for attention to their machines.

In conclusion it must again be stated that although these data were not obtained for large numbers of workers over long periods of time, yet they do represent a fair sample under various conditions and on various types of work. In no case did any evidence appear of increased fatigue, shown by a decrease of output, or of increased slackness, shown by an increased loss of time, as the result of a change from day-work to shift-work.

III. The Effects upon the Worker of the Two-Shift System.

It is necessary to deal with a number of effects of shift-work which are as a rule less immediately present to the minds of the management because they are to some extent connected with the lives of the workers outside the factory. These are the effects of shift-work upon time-keeping and absenteeism, upon sickness, and upon labour turnover, which depends on the goodwill of the workers and their readiness to work in shifts. In the first place it will be necessary to deal with the obvious aspects of these questions, which have when possible been gauged statistically ; and then to consider their contributory causes.

Lateness and Absenteeism.

At Factory A records were kept of the amount of time lost by lateness and absence from the factory without leave for causes other than sickness. Data for 76 day-workers and 188 shift-workers taken over a period of two years showed that the day-workers lost 2·0 hours per worker per week and the shift-workers, 2·6 hours ; the difference, 0·6 hours, (p.e. $\pm$ ·046), is statistically significant. But the weekly working hours of the day-workers were $45\frac{1}{4}$, and of the shift-workers, $40\frac{1}{4}$. Thus the day-workers lost 4·4 per cent. of their time, and the shift-workers lost 6·5 per cent. The day-workers lost 0·8 per cent. of their time in the form of whole days, and the shift-workers lost 1·1 per cent. Thus of the difference of 2·1 per cent. between day and shift-workers only 0·3 per cent. was lost in the form of whole days, and the remainder by lateness or absence of a few hours. That is, the difference between the time lost by the day and shift-workers was 38·5 per cent. of the average time lost by both ; and of that 38·5 per cent. only 5·5 per cent. was accounted for by the loss of whole days.

At Factory B it was found that there were 6 per cent. more cases of lateness among the day-workers than among the shift-workers. But among the day-workers the amount of time lost was rarely more than a quarter or half-an-hour; while 9 per cent. of the cases among the shift-workers averaged a loss of $1\frac{3}{4}$ hours. It was impossible to get an exact comparison of the number of hours lost, but it appears that in about a tenth of the cases of lateness, the workers, instead of coming on at 6 a.m., waited and came on with the day-workers at 8 a.m.

Sickness.

No conclusive statistical evidence has been found of a greater amount of sickness on one system than on the other. In Table VI are given the number of visits during one year to the First Aid Station at Factory A of fourteen hundred to two thousand workers. The visits were tabulated firstly in three groups, for departments always on shift-work, departments always on day-work, and departments changing from shift-work to day-work, or *vice-versa*, during the year. Secondly, all the departments were taken month by month and assigned to one of two groups, according as they were on shift or day-work during that month. The figures given for 'All Shift-Workers' and 'All Day-Workers' are thus the average, per 100 workers per annum, of the number of visits in each month by all shift-workers and all day-workers. The differences of these averages are also given, together with the probable errors of the differences calculated from the monthly deviations from these averages.

When the visits were grouped by departments, it appeared that the total sickness of the departments on shift-work was exactly the same as that of the departments on day-work. There were more accidents in the former group, because the workers in this group were employed on machine work where it was more easy to incur accidents; while the day-workers were many of them employed on the work of grading silk, where there was no risk of accident. There were more cases of faintness and of disorders of the digestive system among the shift-workers than among the day-workers; but owing to the large monthly variations in the number of cases, this difference did not appear to be statistically significant.

The visits were also tabulated according to the hour of day at which they occurred. There was no evidence that there were any more cases of faintness early in the morning, or of headaches late in the evening, among shift-workers than among day-workers—or, indeed, of any more sickness of any kind. At Factory B, it appeared that only half as many days were lost through sickness by the shift-workers as by the day-workers; and that there were only about half as many visits to the First-Aid Room.

TABLE VI.—*Number of visits to First Aid Station per 100 workers per annum (250 full working days, Saturdays, Sundays and Bank Holidays omitted).*

	Causes of Visits.							Total omitting Acci-dents.	Total Visits.
	All Acci-dents.	Respira-tory Diseases.	Head-ache and Neuralgia.	Faint-ness and Dizzi-ness.	Dis-orders of Digestive System.	Menstru-ation.	Other Causes.		
Departments always on shift-work ..	42	13	26	9	14	18	21	101	143
Departments always on day-work ..	30	11	25	6	9	24	26	101	131
Departments changing from shift-work to day-work (or *vice-versa*).	38	13	29	10	10	21	19	102	140
Difference between departments on shift-work and departments on day-work.	12	2	1	3	5	−6	−5	0	12
All shift-workers	42	13	26	9	13	19	23	103	145
All day-workers	29	11	24	7	10	21	19	92	121
Difference	13 ±4·3	2	2	2 ±1·2	3 ±1·4	−2	4	11 ±6·0	24 ±8·2

Since one of the causes of illness might have been deficiency of sleep, an attempt was made to gain some knowledge of the hours spent in bed by questioning samples of the workers (numbering 200 in all) in Factories A, B, C, and D. So far as reliance can be placed on this method of investigation, the data show that six-and-a-half to seven was the most usual number of hours spent in bed, that more than half the workers spent less than seven hours in bed, and that almost all spent less than eight hours in bed. The time of getting up in the morning seemed to vary less than one might have expected from the length of the journey to the factory; it was usually about an hour before work began. The majority of the workers appeared to go to bed before 11 p.m. On the other hand, three-quarters of the workers stayed in bed till 9 o'clock or after when they were on the afternoon shift, and this, no doubt, helped to redress the balance. Moreover, it appeared that (except at Factory C where the hours spent in bed were longer), the majority of the workers used to lie down in the afternoons when they were on the morning shift, either regularly, or occasionally when they felt the need of it.

A similar method of inquiry was adopted in order to ascertain to what extent an adequate meal was taken before starting work. It appeared that about half the workers had a proper breakfast before leaving their homes, and that about a quarter had nothing to eat, preferring to wait until the ordinary meal-break in the shift, though most of these had a cup of tea.

Another possible cause of sickness would be the amount of house-work done at home in addition to work at the factory. It was found that, though about a third of the workers did none at all, a quarter did regular house work. But it may be noted that at Factory C, scarcely any house work was done, owing to the unusual system of hours worked there (See note to Table V.)

Labour Turnover.

Last of all must be considered the labour turnover, which gives the surest sign whether the workers are satisfied or not with their employment. Only in one or two cases was any complaint made of a high turnover among shift-workers; and this was when the number of shift-workers was small, and the system in operation for a short time only. On the other hand it was several times said with pride, "Our girls never leave except to get married." It was fortunately possible to get a statistical measure of the effect of shift-work upon the labour turnover at Factory A, where the conditions were most favourable for shift-work, and where the system was in force on a large scale.

In Table VII are given the results obtained from these data The various departments were placed in three groups in the same way as in Table VI. The average monthly turnover for each group is the sum of the numbers leaving from the departments in

that group in each month divided by the number in employment in those departments in that month. The yearly turnover is the total number of workers leaving during the year divided by the average number in employment during that year. The former is the more accurate measure, owing to the constant variation in the number of workers employed, and probable errors are therefore calculated upon it. The second measure gives a more general impression. These figures do not include the workers "laid off" from shortage of work; they formed a further 10 per cent. per annum.

TABLE VII.—*Labour Turnover for a Period of One Year.*

	Average Turnover per month per 100 Workers employed.	Average Turnover per annum per 100 Workers employed.
I. Departments always on shift-work ..	4·1	47
II. Departments always on day-work ..	2·6	30
III. Departments changing from shift to day-work (or vice-versa) during the year.	6·6	77
Difference between I and II	$1{\cdot}5 \pm 0{\cdot}66$	17
Difference between I and III	$2{\cdot}5 \pm 0{\cdot}66$	30
Difference between II and III	$4{\cdot}0 \pm 0{\cdot}66$	47
Difference between I and II combined and III.	$3{\cdot}2 \pm 0{\cdot}57$	41

It appears that out of about sixteen hundred workers on the average fifty in every hundred left every year. This is a very large figure. The difference of turnover between the groups of departments always on shift or day-work repectively was not large enough to be statistically significant. But the turnover in departments which had changed over from day to shift-work, or *vice-versa,* during the year was very considerably larger than the turnover in either of the two former groups. Indeed, three-quarters of the workers from these changeable departments left during the year. One possible explanation of this is clear. The unsettled conditions set up by a change from day to shift-work or *vice-versa,* produced a large turnover, because the bodily habits acquired under one regime differed from those necessary under the other, and a change-over was upsetting to these habits. This explanation received support from the fact that about three-quarters of those who left did so at their own request.

If we study the opinions in favour of or against shift-work, which were collected systematically from samples of the workers, we find evidence of the same importance of well-developed habits.

In Factory B, where the majority of the workers had been on shift-work for six months or less, 90 per cent. of the workers questioned preferred day-work. At Factory C, where, it must be remembered, the shifts were differently arranged, but where the system had been in operation for some years, 90 per cent. of the workers preferred shift-work. At Factory A, where the majority of the workers questioned had been on shift-work for some time, three-quarter of the workers preferred shift-work. At Factory D, the workers who had been on shift-work for some years said they preferred shift-work; those formerly on shift-work who had changed and had been on day-work for about a year now preferred day-work. It is true that when questioned, only a few gave as their only reason for their preference for shift or day-work the fact that they were used to it; but this was the first reason given by several, though they were able to give other reasons when pressed further. Again, many workers, though quite certain which type of work they preferred, could give no reason for their preference; the probability is that they preferred the hours to which they had become accustomed.

Thus it appears that the most potent factor in producing a preference for day or shift-work was habit. The other reasons cancelled out—that is to say, there were as many on one side as there were on the other. It seemed, then, that if the shift system was kept going steadily for some length of time, without frequent changes from shift-work to day-work, the workers became accustomed to it, and it ran smoothly.

IV. Summary.

(1) The operation of the two-shift system (as compared with a day system of 8 a.m. to 6 p.m.) was studied in detail in eight factories, employing in all about 2,400 workers on shift-work.

(2) The few comparable data available suggest that the rate of work was often increased when workers were employed on the two-shift system. Owing, however, to the shorter hours worked by the shift-workers (on the average $40\frac{1}{4}$ hours compared with 46 hours), the *weekly* output per worker was lowered by 4 per cent.

(3) A comparison of the lost time records in one factory suggests that absenteeism amongst the shift-workers was greater than amongst the day-workers.

(4) Neither system was shown to have any advantage over the other in respect of the sickness experienced. So far as could be ascertained by questioning the workers, a deficiency of sleep during the week of morning shifts was usually compensated for during the week of afternoon shifts.

(5) In one large factory it appeared that the labour turnover was slightly greater in departments always on shift-work than departments on day-work. But in departments in which there were changes from day to shift-work and *vice-versa*, the turnover was approximately twice as great.

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Its Effect upon the Sickness Rates of Weaving Operatives.

By A. BRADFORD HILL, Ph.D.

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PREFACE.

The introduction of moisture by artificial means into the air of cotton weaving sheds in which certain kinds of cloth are woven has for many years been the subject of controversy in the industry. In view of the continuous objection of the operatives to the practice, especially during the hotter months of the year, the use of artificial humidity has long been controlled by statutory requirements, the existing regulations (which allow artificial humidification within certain limits) having been made on 21st December, 1911, under the Cotton Cloth Factories Act of that year.

Since that time, the demand for the complete abolition of artificial humidification as being injurious to health has been frequently renewed by the operatives, and has been opposed by the employers on the grounds that it is essential to the production of certain kinds of cloth. The question accordingly was on several occasions further discussed at conferences between representatives of the Home Office, employers and operatives with a view to securing agreement as to the limits within which artificial humidification should be allowed. These conferences, however, failed to come to an agreement, one of the principal difficulties being that no definite evidence was forthcoming to show how far humidification within the limits allowed is, in fact, injurious to health, or whether there is more sickness amongst weavers in artificially humidified sheds than amongst those in which this practice is not adopted.

Accordingly, at the request of the industry, the Secretary of State in November, 1924, appointed a Departmental Committee under the Chairmanship of Mr. John Jackson, H.M. Deputy Chief Inspector of Factories, "to consider and report whether any, and, if so, what modifications of the existing statutory regulations governing the use of artificial humidity in cotton cloth factories are desirable and practicable." On the recommendation of this Committee the Home Office approached the Medical Research Council with the request that the subject of sickness incidence amongst weavers in the Cotton Industry should be investigated by the Industrial Fatigue Research Board.

The advice of the Statistical Committee of the Medical Research Council was first sought on the best method of procedure, and it quickly became apparent that the inquiry presented special difficulties of its own and that if any comparison between so-called humid and dry sheds in respect of sickness rates were to be reliable, close consideration of the technique to be adopted would be necessary. It was accordingly agreed to refer the general direction of the investigation, which was entrusted to Dr. A. B. Hill, to a small joint Committee composed of representatives of the Statistical Committee and of the Departmental Committee on Humidity.

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Eventually the following procedure was adopted. In the first place, a list of humid and dry sheds, agreed upon by the employers and operative members as representative, was obtained from the Departmental Committee on Humidity. The firms specified in this list were approached, and facilities for investigation were obtained in 127 sheds, situated in Blackburn, Nelson, Accrington, Burnley and Preston, covering in all over 20,000 weavers.

Investigation then proceeded on the following lines :—

(1) For each weaver in employment on 1st August, 1925, certain particulars as to name, age and Approved Society were filled in by each employer concerned

(2) In order to allow for unequal " exposure to risk " on the part of weavers ceasing work during the year under inquiry, the employers concerned furnished quarterly lists of " exits," containing the name of each weaver concerned, the cypher number of his Approved Society, and the date of exit.

(3) At the expiry of twelve months the cards were submitted to the appropriate Approved Societies, who supplied, in respect of each weaver, details of the sickness experienced during the year ended 31st July, 1926.

As will be seen from the report itself, the data so obtained when treated by appropriate statistical methods have not disclosed any significant difference between the sickness rate of weavers in the sheds concerned, whether these sheds are distinguished merely as humid and dry, or are classified on the basis of their actual temperatures and humidities.

Whilst this result is of great importance, in the opinion of the Board, the investigation is also of interest in furnishing a measure of the sickness incidence in the particular industry concerned, and so laying the foundation for a comparison between cotton and other industries, as similar data are collected in other occupations.

The investigation was made possible only by the collaboration of others, and the Board would express their great indebtedness to the Insurance Department of the Ministry of Health and to H.M. Inspectors of Factories for the Districts concerned for much valuable guidance and assistance at the inception of the inquiry, to the managements of the different sheds for their willingness to give facilities and to supply information, to the different Approved Societies for the sickness data furnished at the cost of considerable clerical labour, and lastly to the Joint Committee already referred to under whose general supervision the inquiry was held.

November 1927.

Artificial Humidification in the Cotton Weaving Industry.

Its Effect upon the Sickness Rates of Weaving Operatives.

By A. BRADFORD HILL, PH.D.

INDEX.

INTRODUCTION.

It is stated that in the manufacture of cotton cloth a relatively high percentage of moisture in the air is required for good weaving. In a dry atmosphere the cotton strands are more liable to break. This, in part, is the explanation of the localisation of the industry in Lancashire where the prevailing winds and geographical configuration are such as to fulfill this need. Some manufacturers hold that for the successful weaving of certain classes of cloth natural humidity is not sufficient, and a practice has been introduced of injecting additional moisture into the air of the weaving sheds either in the form of water or of steam. This practice has met with strong opposition from the organisations of the operatives, the protests of which have led to several Parliamentary inquiries into the conditions. These inquiries have resulted in certain statutory regulations Amongst other things the limits of humidity permissible at various temperatures are now prescribed. The successive stages of this legislation have been traced in the preface to the Board's report upon Atmospheric Conditions in Cotton Weaving,* and it will suffice to give here a very brief summary of its history.

The first official mention of artificial humidification is to be found in a report made by Dr. Buchanan in 1872, following on a protest made in 1871 by Todmorden weavers against heavy 'sizing.' A protest against the artificial humidification of weaving sheds followed in 1882, made by the Parliamentary Committee of the Trade Union Congress. An official inquiry was held and recommendations made for ensuring a sufficient standard of ventilation.† These recommendations were followed by an Act of 1889‡ and at the same time, as a result of further inquiries, the maximum limits of humidity permissible in the atmosphere for different temperatures were tabulated. Still dissatisfied, the Weavers' Associations in 1896 renewed their demands for the abolition of artificial humidification. Further investigation was made by a Departmental Committee, the result of which was the introduction of important provisions relating to temperature and ventilation.§ In order to reduce the rise of temperature within the sheds the white-washing of the roofs in summer and the lagging of the steam pipes were made compulsory, whilst, as regards ventilation, a chemical standard of purity was introduced and sufficient means were required to maintain this standard. No change was made in the permissible limits of humidity.

In 1906 a ballot was taken by the Weavers and showed a large majority in favour of abolition of artificial humidification. Another Departmental Committee was appointed with wider and

* Industrial Fatigue Research Board Report No 21 Atmospheric Conditions in Cotton Weaving. By S Wyatt, M Sc.

† Report on the Effects of Heavy Sizing in Weaving on the Health of the Operatives, 1884 (C 3861.)

‡ Cotton Cloth Factories Act, 1889. (52 and 53 Vict. Chap. 62.)

§ Report of Committee appointed to inquire into the Work of the Cotton Cloth Factories Act, 1897. (C. 8348)

more detailed terms of reference. The principal recommendations made by this Committee* are summarised in the Board's Report No. 21, as follows :—

(*a*) The permissible relative humidity is defined in terms of the difference between the dry and wet bulb temperature. Below 70° F. this is limited to two degrees, and above 70° F. to an increased amount on a graduated scale.

(*b*) The introduction of humidity is prohibited when the dry bulb temperature is below 50° F., or the wet bulb temperature is above 75° F.

(*c*) A standard of efficiency is prescribed for the material to be used for the lagging of steam pipes.

(*d*) With the object of lessening the quantity of steam introduced into the air, the standard of ventilation is relaxed from 9 volumes of carbon dioxide per 10,000 volumes to 8 volumes in excess of the outside air (roughly equivalent to 12 volumes absolute).

To give effect to these recommendations a special Act† was passed. These are the regulations in force at the present day.

This legislative action has failed to effect a complete settlement, and the operatives have renewed their requests for the abolition of artificial humidification.

The Board's Report on Atmospheric Conditions in Cotton Weaving (previously cited) was a further step forward in knowledge of the environmental conditions in which the weaving operatives are at work. As far as conclusions can be drawn from the investigation of sample factories, it showed that, according to modern standards, " in humid cotton-weaving sheds the physical conditions of the workers' environment do not reach the standard which ought to exist, and which is, in fact, attained in other, though not in all, industries. The physiological effects of these conditions have already been explored in previous inquiries, the results of which go to show that long continued exposure may produce discomfort, and tend to a low state of heatlh."‡ This report did not, however, make any contribution towards a solution of the long-drawn out controversy as to whether these conditions besides causing discomfort do actually contribute to the amount of ill-health suffered by the workers. " No conclusive evidence on the subject has ever been obtained, and, indeed, the lack of any real information relating to it is emphasised by each of the Departmental Committees which have successively dealt with humidity in weaving."§ The present investigation, the results of which

* Reports of the Departmental Committee on Humidity in Cotton Weaving Sheds First, 1909 (Cd. 4484). Second, 1911 (Cd. 5566).

† The Factory and Workshop (Cotton Cloth Factories Act, 1911). (1 and 2 Geo. 5, Chap. 21.)

‡ Industrial Fatigue Research Board Report No. 21. Atmospheric Conditions in Cotton Weaving. p vii.

§ Ibid. p. viii.

are given in this report, has been undertaken for the purpose of supplying this essential information. Its object is to determine the actual sickness incidence in a large sample of " humid " and " non-humid " weaving sheds. This will allow a comparison to be made between the amount of sickness found in mills into which artificial humidification is introduced with the amount found in mills in which this practice is not in force. In the absence of any other dissimilar contributory factors in the two types of sheds, this will enable the effects of artificial humidification upon health to be assessed.

Method of Investigation.

Determination of the Exposed to Risk.

The weaving sheds chosen for investigation were situated in five Lancashire towns, Preston, Burnley, Blackburn, Nelson and Accrington. In Preston, Burnley and Accrington are to be found weaving sheds of both types—those that use some method of artificial humidification, the humid or " wet " sheds, and those that make no such addition to the natural moisture already present in the air, the non-humid or " dry " sheds. In Blackburn the type of cloth woven demands a high humidity, and all the sheds in the district use artificial humidification. In Nelson the position is reversed, and all the sheds in the town belong to the " dry " category.

It is, however, obviously not sufficient to compare the sickness experience of the wholly wet town, Blackburn, with that of the wholly dry town, Nelson. If such a comparison revealed a significant difference of sickness rates it would not be certain that artificial humidification was the decisive factor in producing such a result. Some other environmental factor may equally well exist—for example, housing conditions—and such other factors cannot be easily differentiated from that of humidity. For this reason choice was made of the other towns, Preston, Burnley and Accrington, in which both processes exist side by side, and in which there is no reason to suppose that other environmental factors will not be similar. A significant difference between the sickness rates of the dry sheds and those of the wet sheds in one and the same town can be ascribed with more confidence to the effect of humidity.

On the other hand, owing to the dislike which it is said exists amongst the operatives to working in sheds into which humidity is introduced, it has been argued that in a town where both types of sheds exist the better and stronger workers may secure work in the dry sheds and a weaker population be forced to be content to work under humidified conditions. In other words, there may be a selective influence tending to produce a population in the wet sheds more liable to sickness than that found in the dry sheds. If this contention were true any excess of sickness found in the wet sheds could be ascribed to humidity only in a very

indirect fashion. To overcome this argument the wholly wet and dry towns were chosen. In each of these there can be no selective influence; all weavers must work in wet sheds in the one and in dry sheds in the other. It has been pointed out that other environmental conditions may exist and make comparison difficult but a selective force is, at least, obviated.

Having chosen the towns on this basis a sample of mills, agreed upon by the representatives of the employers and employees, was selected within each, and the employers in these mills were asked to co-operate in the investigation. With very few exceptions the necessary permission was given. The employers were then supplied with cards and asked to provide a complete "Census" of the *weavers** employed by them on 1st August, 1925.† A separate card was completed for every weaver, and the employers supplied on each the following details:—

(1) The name of the firm and mill, and the town in which it was situated. (2) The name of the shed in which the weaver worked, if the mill was made up of more than one. (3) The operative's name, initials, and sex. (4) The cypher number of the Approved Society to which the operative belonged (under the National Health Insurance Acts) and his (or her) membership number within that Society. These numbers the employer obtained from the operative's National Health Insurance card. (5) The number of looms normally attended by the operative and the number actually attended at 1st August, 1925. The answer to this query it was considered might give some indication as to the abnormality of conditions within the sheds due to trade depression.

In all 74 firms took part in the inquiry, and the number of separate sheds was 128. The number of weavers at work in these sheds was 20,133‡ (4,971 males and 15,162 females). In Table I is shown the distribution of these firms, sheds, and operatives according to towns and the humid and non-humid category.

The object aimed at was to obtain, roughly, equal numbers for each sex in each type of mill. Actually, there is a preponderance of males in the non-humid sheds and of females in the humid

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* No other workers, e.g., tacklers, tenters, workers in the preparatory departments, or warehouse were included

† Actually the cards were completed mainly over the first three weeks of August. This means that in a few cases a weaver may have been included who was not employed in the mill on August 1st, but joined it at some date during the first three weeks of August As the exposed to risk has been calculated for all persons as from August 1st, a very slight error would be here introduced, but so slight as to be entirely negligible in influencing the results.

‡ The total number of cards actually returned was just under 500 larger but these 500 had to be deleted for various reasons, e g., they related to persons below or above the insurable age or sufficient details could not be obtained to enable the Approved Societies to identify them.

TABLE I.

Town	No of Firms co-operating		No. of Sheds.		No. of Operatives			
	Humid	Non-Humid	Humid	Non-Humid	Humid		Non-Humid.	
					Male	Female	Male	Female
Preston ..	13	10	23	14	317	2,843	308	1,767
Blackburn ..	12	—	20	—	513	1,756	—	—
Burnley .	10	10	18	16	1,142	2,211	1,179	2,583
Nelson ..	—	9	—	14	—	—	1,388	1,555
Accrington	9	3	15	8	97	1,766	27	681
All Towns	44	32	76	52	2,069	8,576	2,902	6,586
All Towns Humid and Non-Humid	76*		128		20,133			

* Actually the number of firms co-operating was 74, but two having both humid and non-humid sheds were entered under both categories

sheds. The males, it will be observed, amount to only one-third of the females, and Nelson is the only town in which the two sexes approach any equality in numbers. The total, 20,133, representing the number of weavers found in these mills on 1st August, 1925,* is the total of weavers whose sickness experience was investigated. No additions were made to it of weavers who became employed in these mills after 1st August, 1925, or, to use the technical term, no "entrants" were added to the original population. The sickness experienced by these weavers was investigated for one year, from 1st August, 1925, to 31st July, 1926. Obviously all these operatives would not remain employed during the whole of this year in the mill in which they were working on 1st August, 1925. Some would move to other mills, some would leave the industry, some would die. Account has to be taken of this. The "sickness history" of each worker is required only as long as he (or she) is working in the particular shed in which he was found on 1st August, 1925. If he leaves this shed during the year of inquiry nothing is known of the conditions to which he has gone, and his sickness history can no longer be related to the humid and non-humid conditions. For instance, a weaver may have been returned on 1st August, 1925, as a worker in a dry shed in Burnley; on 30th October, 1925, he leaves that shed and, perhaps, finds employment in a humid one in Accrington. In this case the only sickness history with which the investigation is concerned is that between 1st August and 30th October, 1925, to which the shed conditions under which the operative was working can be related. The procedure adopted in this investigation does

* Vide note, p. 6.

not provide any knowledge of this weaver's environment *after* 30th October, 1925, and, accordingly, any sickness after that date is not within the scope of the inquiry. If such later sickness were to be included in the example cited, it would be attributing ill-health actually suffered in a wet shed to employment in a dry shed, which the worker had previously left.

For this reason each employer was asked to supply a list of all the weavers whose names were included at the "Census" on 1st August, 1925, who ceased to be employed by him after that date. Any operative whose absence was only temporary, through sickness or any other cause, was not to be included in this list, but only those who definitely ceased to work in the mill in which they were found at the date of the "Census." To avoid omissions and enable any doubts to be cleared up without delay this return of "exits" was made by the employers every quarter. The information required was the name and insurance numbers of the weaver, to enable the investigator to identify the particular operative, and the date at which the weaver left the mill. In addition, in case the conditions in any mill were such as to induce persons who fell sick to leave their employment there, and thus produce a "select" population in the mill (selected for their resistance to sickness), a question was included as to whether the weaver was sick or not at the date of leaving. In practice it was found that this would not always be known to the employer, and the information supplied on the point from this source is not sufficient or accurate enough to warrant its use. The same information can be obtained, however, from the sickness history as supplied by the Approved Societies. From the data thus supplied by the employers—the enumeration of the weavers employed by them on 1st August, 1925, and a list of those who ceased to be employed by them during the year following that date—the total "exposure to risk" can be calculated. It will consist of so many operatives who were "exposed" for the whole year of inquiry *plus* the fractional amount of a year for which each "exit" was exposed.* The error to which this calculation is liable depends upon the accuracy of the employers' returns of "exits."

If omissions have occurred from those lists, i.e., if weavers have left a mill and not been included in the quarterly return, or if the date of exit is incorrectly given, this will introduce some error into the figure obtained for the exposed to risk. Examination of the quarterly returns showed that some omissions were certainly existent, the accuracy of the return varying from mill to mill. To overcome this error each employer (the accuracy of whose returns there was reason to doubt) was supplied, at the end of the year of inquiry, with a list of the weavers enumerated as being employed by him on 1st August, 1925. Those weavers who had

* An adjustment has to be made for those operatives who were not qualified for benefits under the National Health Insurance Act until after 1st August, 1925. This will be referred to later.

been returned as exits during the year were marked as such on this list, and the remaining names were checked by the employer. If these names all related to weavers still in the mill obviously no omissions had been made in the quarterly returns ; if such was not the case, an additional return was made. This precaution, it is thought, has reduced the omissions to a relatively small figure, although it did not succeed in entirely eliminating them.*

From other sources of evidence† it was known that the date of exit given was constantly likely to be somewhat in error, but that this error would rarely exceed a fortnight. It may be given as before or after the true date of exit, and there is no apparent bias in either direction, or in either type of mill, dry or wet.

In a time of bad trade when workers are constantly " standing off," the employer cannot be certain whether they will find work elsewhere or return to his mill, and the date of exit is not one that can easily be given with absolute accuracy. It would, in many cases, be unreasonable to demand it. The question at issue is, knowing such error does exist, is it likely to be of such magnitude as to have any appreciable effect on the conclusions reached ? The considerations to be borne in mind are (1) there is no apparent bias towards giving the date of exit uniformly earlier or later than the true date of exit ; it may fall on either side, so that *as a whole* the exposure to risk will be unaffected ; (2) there is no apparent bias to error in either type of mill so that a *comparison* between wet and dry mills is unaffected ; (3) the total number of exits, 2,239,‡ is only a proportion of the total exposure (roughly one-ninth) and the accuracy of the much larger proportion will outweigh the slight inaccuracies present in the smaller, so that the final results reached will only be liable to an unimportant error In addition, the exits who suffered sickness during the year are a smaller proportion. From these considerations it does not appear that the inaccuracy of date of exit is at all likely to vitiate the final comparison of rates in wet and dry sheds §

The total exposure to risk was reduced by four mills (one in Blackburn and three in Accrington) closing down during the year of inquiry, owing to bad trade conditions and the coal dispute of 1926 In these cases the weavers employed in the mill had all to be taken as exits at the date at which the mill ceased to work.

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* This is known from further information obtained after the completion of the year's inquiry.

† e g , from information supplied by the Approved Societies.

‡ This number does not include those whose exposure was reduced through a whole mill closing down or for reasons connected with National Health Insurance for the question of accuracy of date does not occur in these cases. It is the number of exits returned by the employers on the quarterly lists.

§ It will be observed, too, later in the report (e.g., Table V) that figures based only upon persons exposed for the whole year give the same general result as do those based upon all the exposed to risk, whole-year persons and exits.

The dates at which these mills shut down and the number of weavers affected and taken as exits at the date of closing were as follows:—31st December, 1925, 150 weavers; 31st January, 1926, 94 weavers; 16th April, 1926, 107 weavers; 5th June, 1926, 424 weavers. This increases the number of weavers exposed for only a part of the year of investigation to 3,014 (roughly one-seventh of the total number). It appreciably reduces the exposed to risk in the dry sheds in Accrington, where the population of weavers returned is already a small one.

Having thus secured the details of the population at risk in either type of mill, it remains to obtain an accurate sickness history of the population for the year—1st August, 1925, to 1st July, 1926—and finally to relate the one to the other.

The Acquirement of the Sickness History.

To acquire knowledge of the sickness experience of each weaver during the year of investigation the co-operation was sought of the Approved Societies (acting under the National Health Insurance Acts) to which the weavers belonged. In all, over a hundred societies had to be approached though in many cases only one or two members were concerned. The main bulk of the weavers belonged to some thirty societies, three or four of which had over a thousand members concerned, while the largest trade union society connected with the weaving industry had to complete over one-third of the total number of cards—about 7,500. The details required were supplied voluntarily, and every facility was given to the investigator. The inquiry owes much to the readiness with which these societies lent their aid. The procedure was as follows:—When the details required from the employers had been entered upon the cards, the cards were returned to the investigator and sorted according to the Approved Societies to which each related (the cypher number of the Approved Society to which each weaver belonged was one of the details required of the employer). The cards were then sent to the appropriate societies at or just before the end of the year of inquiry (31st July, 1926) and the required information inserted from the data in the possession of these societies. The questions that were answered for each member and the considerations that made them necessary were as follows: (1) Date of birth. This enables the exposed to risk to be classified according to age, an important point as sickness increases fairly steadily with age, so that in an accurate comparison of the sickness experience of two populations the age distribution is a vital factor. (2) Civil state in the case of women. The sickness suffered by married women differs widely from that of single women* (due in part to claims

* Vide, for example, National Health Insurance: a Statistical Review, by Sir Alfred W. Watson, K.C.B. *Journal of the Royal Statistical Society.* Vol. XC. Part III. 1927. pp. 451–2.

connected with maternity), and it is thus necessary to separate the two groups. (3) If married woman, date of marriage. Some women would become married during the year of inquiry, and in these cases date of marriage would allow them to be transferred from the single to the married group. (4) Number of contributions paid under the National Health Insurance Act for the contribution years 1923–24 and 1924–25, and the dates at which the operative became qualified for sickness benefit and disablement benefit if these dates fell after 1st August, 1925, the date at which the inquiry began. The information supplied on this point enables a correction to be made to the exposed to risk for those persons who were not already qualified for benefit at the date at which the inquiry began. Under the Act each insured person has to be in insurance 26 weeks and to pay 26 contributions before becoming qualified to receive sickness benefit, and 104 weeks and to pay 104 contributions before becoming qualified to receive disablement benefit (the definitions of sickness and disablement are dealt with later). Where a person is not so qualified there would be a tendency, as no benefit could be drawn, not to notify the society of any sickness undergone. Accordingly, there is some doubt in such cases as to whether the sickness history is complete, and it is a safer policy not to include them amongst the exposed to risk, either for "sickness" or "disablement," until such date as they are fully qualified to draw benefit. The dates supplied by the Approved Societies enable this to be done. (The dates are, in some cases, liable to some slight error, not sufficient to influence results.) The age-group mainly concerned is 15 to 20 years, the years during which persons first enter insurance. The number of such cases falling outside this group is relatively very small. The total number of persons who did not quality till after the beginning of the year of inquiry and for whom this adjustment has been made is 498 for sickness and 2,438 for disablement * This, again, increases the number of persons who were not exposed for the whole of the year of investigation and brings it for sickness to 3,449 (one-sixth of the total), and for disablement to 5,017 (one-fourth of the total).† (5) The main requirement from the Approved Societies was the invalidity experienced by each weaver during the year 1st August, 1925, to 31st July, 1926, giving dates at which sickness or disablement began and ended, precise nature of the incapacity including any change of diagnosis during incapacity, distinguishing "sickness" and "disablement," and detailing "linked-up" sicknesses previous to the year of inquiry. The sickness history given in this form can be related accurately to the number of persons exposed to risk. The duration of each period of incapacity is calculated, and thus the total

* For disablement in many of these cases the operative was unqualified during the whole of the year.

† The number of persons not qualified must not be directly added to the number of exits as some persons fall in both categories—they did not qualify till a date after 1st August, 1925, and later became exits.

amount of morbidity suffered is computed. Information as to nature of incapacity enables some comparison to be made between the prevalence of various causes of illnesses in the two types of mills, and it can be ascertained thus whether any significant differences exist that may be due to humidity.

Reference has been made several times to "sickness" and "disablement" and definition of these terms is required. This may be found in the National Health Insurance Act of 1924. By the statutory provisions therein it is laid down that sickness benefit (15*s.* a week for a man, 12*s.* a week for a woman) is given only for a period or periods of sickness not exceeding 26 weeks. After 26 weeks' sickness benefit has been received, if illness still continues it is termed disablement, and benefit is payable on a lower scale (7*s.* 6*d.* a week for a person of either sex). It has already been pointed out that an employed person becomes qualified for sickness benefit at an earlier date than that at which qualification for disablement benefit is reached, and this difference naturally produces a disparity in the numbers exposed to risk of sickness and exposed to risk of disablement. It would be possible to combine the two if the population exposed to risk was limited only to those who were qualified for both benefits. This would, however, reduce the number exposed and eliminate a certain amount of the incapacity experienced, and the better plan is to calculate the two rates separately.

Under the terms of the Act sickness benefit begins on the fourth day of incapacity, unless the claimant has received sickness benefit within the previous twelve months. In the latter case the illness is termed a "linked up" sickness, and benefit begins on the *first* day of incapacity. In calculating the 26 weeks' duration of sickness after which disablement benefit begins, such linked-up, sicknesses are counted as one, i.e., the second illness is treated as a continuation of the first, so that the 26 weeks' maximum may be reached by a series of short linked-up sicknesses. A break of twelve months between sicknesses is required to nullify this process of linking-up.

In calculating the duration of sickness experienced in this inquiry *the date of onset of illness has been taken* and *not* the date at which benefit first became payable. In cases of sickness not linked-up, benefit is not payable till the fourth day of incapacity, while if linked-up it is payable on the first day, but for the purposes of calculation of duration of sickness in this investigation, the first day of incapacity in either case was the date adopted. It must be observed that the provisions of the Act tend to exclude sicknesses of less than three days' duration, except where such sickness is linked-up with a previous one, so that the total amount of incapacity recorded is a little in defect of the true amount suffered. Some Societies pay, as an additional benefit, for the first 3 days of sickness, when no benefit is normally due, but no such Society was involved here.

(6) A final point upon which the Approved Societies were requested to give information related to members who belonged to their Society for only a period of the year of inquiry and transferred during the year to another Society. In such a case it is obvious that the Society would be able to give information as to sickness experience only for the period before transfer took place. For the sickness history after transfer reference would have to be made to the second Society. In some cases, where special facilities existed, this was done, but in others the additional labour involved could not be justified, and these operatives have been treated as exits at their date of transfer. The number thus involved is only 35. This gives the final totals of persons exposed to "sickness" (as distinct from disablement) as follows:—Persons exposed for only a *part* of the year of investigation, 3,484; persons exposed for the *whole* year, 16,649

After this description of the methods adopted to obtain the exposed to risk in the two groups, the humid and the non-humid, and to secure their sickness history over the period of a year, it remains to relate one to the other in such a way as to give a clear comparison of the sickness incidence under the two environments.

Comparison of the Sickness Incidence in all the Humid and the the Non-Humid Sheds.

For accurate comparison with such relatively small numbers fairly broad age groupings must be adopted. If the exposed to risk in any group is too small no reliable statistical ratio will be given and the sickness rate will be liable to chance fluctuations, becoming meaningless. The grouping adopted is ten-yearly (which leaves a final group of 5 years from age 65 to 69). The insured population (by the provisions of the Act) lies between the ages of 16 and 70—entry is made on or after the 16th birthday, exit upon the 70th birthday. In this investigation the first group begins at 15 as the age calculated was age *last birthday* on 1st August, 1925. This has the effect of including a few operatives who entered insurance (and the exposed to risk) at the age of 16 *during* the year of inquiry and were, therefore, aged 15 last birthday on 1st August, 1925.

A final point remains regarding the calculation of the amount of incapacity experienced. In some cases of exit the date of exit given by the employer falls within a period of sickness as recorded by the Approved Society. In other cases it falls on the day at which a sickness began. In these cases the date of exit has been taken not as that given by the employer but as the date at *which the sickness ended.* Obviously, in such cases the reason for exit was sickness; the operative during that sickness could not have been employed elsewhere, and there is no logical reason for not debiting that sickness to the mill in which it began. Where a sickness began shortly *after* exit it has *not* been so included (except when the employer marked the case as "sick at date of exit"

when the date of exit is obviously in error) on the grounds that, even if the interval be only a few days, it is not known what form of exposure the intervening period provided.*

In Tables II and III are given for the sum total of the dry sheds and the sum total of the wet sheds, for *all the towns* :—

(1) The years of exposure to "sickness" (i.e., first 26 weeks of incapacity)† made up of the number of persons exposed for the whole year plus the sum of the fractions of a year contributed by the exits, plus the sum of the fractions of a year contributed by the persons who did not qualify for benefit till after 1st August, 1925.‡

(2) The total duration of sickness experienced by this population in the year of inquiry.§

(3) The number of sickness claims made during the same period.

(4) The sickness rate and the claim rate suffered by each population.

This information is given for males, females (single and widowed), and females (married), in ten-yearly age groupings. In addition, rates, both in their crude and standardised forms, are given for the total populations of all ages.

The standardised and crude rates require some explanation. If the total amount of incapacity be divided by the total exposure, for all ages in each case, the resulting rate per year of exposure is termed the "crude" rate. Such crude rates cannot be compared one with another unless they are derived from two populations in which the *age distribution is similar*. As invalidity increases with age there will be more illness in a population made up of old people than there will be in one consisting mainly of young people. Hence the fallacy of the crude rate which takes no account of the preponderance of population that may exist in any age group. For instance, if, in the sample population of weavers here dealt with, there were more weavers in the older age groups in the dry sheds than there were in the wet sheds, then naturally higher crude sickness and disablement rates would be expected in the dry sheds than in the wet. But no significance could be attached to

* Actually, as a test, for three towns all sicknesses beginning within a fortnight after exit were included This, of course, made the rates slightly higher, but it had no material effect upon the comparative values in wet and dry sheds.

† Unless stated specifically to the contrary, the terms sickness and disablement have throughout the remainder of the report their technical meanings. The words morbidity, invalidity illness, and incapacity have been employed to cover both forms of disability, sickness and disablement.

‡ In the case of females a further adjustment was made for those who were married during the year of inquiry, their exposure being transferred at date of marriage from the single to the married group.

§ Cases of incapacity coming under the Workmen's Compensation Act were excluded, as Approved Societies have not always full knowledge of such cases.

such a difference. It would be merely a reflection of the dissimilarity in age distribution. The rates in the age groups (as long as the groups are not too broad) are not open to this objection as in them obviously like is being compared with like. In these age groups, however, the population at risk is relatively small, and, therefore, the rates are open to the chance fluctuations of sampling. For this reason it is important to secure as well a rate for all ages which will have a greater stability due to greater numbers, and will, at the same time, take account of the differences in age distribution. This is achieved by the use of the standardised rate. The process is as follows :—A population is selected which in the age distribution of its components may be termed "normal," e.g., the numbers in each age group bear the same relationship one to another as do those in the total population, for instance, of England and Wales, so that compared with the "ordinary" population there is no undue preponderance in any one age group. The selection of the standard is, to a certain extent, arbitrary, as there can be no absolute definition of a "normal" population. The standard selected here is the sum of the exposed to risk both in the wet sheds and the dry sheds divided by two, i.e., the mean of the two groups. This is calculated for each age group and for males, single females, and married females.* To the numbers in each age group in this standard population is then applied the sickness rate as found in the corresponding age group, first in the dry sheds and then in the wet sheds. For instance, the number of males aged 15–24 in the standard population, 628·4, is multiplied by 5·2 and 4·3 the sickness rates in this age group in the dry and wet sheds. This gives the number of days of sickness that a population of this size in this group would suffer if exposed to the same rate as is actually found in each type of mill.

The same process is carried out for each age group, and the amount of sickness thus given is totalled. This total divided by the total population at all ages in the standard population gives the standardised rate for each type of mill. These two rates are directly comparable and represent the rates that would be found in two populations identical in age distribution suffering from the rates found in the separate age groups in the dry sheds and in the wet sheds.

* This gives the standard population as :—

Age group.	*Population.* *Males.*	*Females (Single and Widowed).*	*Females (Married).*
15–24	628·4	2165·5	286·6
25–34	608·6	935·8	1202·0
35–44 . .	386·0	471·9	912·2
45–54	408·2	280·8	438·0
55–64	229·9	123·0	99·1
65–69 . .	41·7	19·9	10·9
All Ages .. .	2302·7	3997·0	2947·7

TABLE II.—*Sickness (first 26 weeks) recorded in total of Non-Humid Sheds in All Towns.*

Age Group (age last birthday) (1)	Person-years of exposure for Sickness. (2)	Total Duration of Sickness* in days (3)	Number of Sickness Claims (4)	Sickness Rate in days per person-year of exposure. (5)	Number of Sickness claims per 100 person-years of exposure (6)
		Males			
15–24 ..	739·9	3,855	145	5·2	19·6
25–34 ..	717·4	5,041	184	7·0	25·6
35–44 ..	439·4	3,376	99	7·7	22·5
45–54 .	450·7	4,301	110	9·5	24·4
55–64 .	265·1	3,639	75	13·7	28·3
65–69 ..	48 6	1,473	17	30·3	35·0
All Ages ..	2,661·0	21,685	630	—	—
Crude Rate..	—	—	—	8·15	23·7
Standardised Rate	—	—	—	8·18	—
Total number of Weavers = 2,902					
		Females (Single and Widowed).			
15–24 ..	1,859·8	13,476	477	7·2	25·6
25–34 ..	841·8	7,459	213	8·9	25·3
35–44 ..	427·4	5,851	128	13·7	29 9
45–54 ..	232·0	2,917	74	12·6	31·9
55–64 .	118·1	2,654	58	22·5	49·1
65-69 ..	18·1	667	8	36·8	44·2
All Ages ..	3,497·2	33,024	958	—	—
Crude Rate..	—	—	—	9·44	27·4
Standardised Rate	—	—	—	9·38	—
Total number of Weavers = 3,746 and 165 single for part of the year					
		Females (Married).			
15-24 ..	248·7	6,032	164	24·3	65·9
25–34 ..	991·1	19,909	525	20·1	53·0
35–44 ..	786·9	15,050	385	19·1	48·9
45–54 ..	364·6	8,414	182	23·1	49·9
55–64 ..	79 7	1,551	37	19·5	46·4
65–69 ..	9·5	580	9	61·3	95·1
All Ages ..	2,480·5	51,536	1,302	—	—
Crude Rate ..	—	—	—	20·78	52·5
Standardised Rate	—	—	—	20·77	—
Total number of Weavers = 2,675 and 165 married for part of the year.					

* In calculating the duration of sickness the *whole* duration of each period of incapacity is used throughout all the Tables in this report, i.e., the first three days for which benefit is not payable *are* included.

TABLE III—*Sickness (first 26 weeks) recorded in total of Humid Sheds in All Towns*

Age Group (age last birthday) (1)	Person-years of exposure for Sickness (2)	Total Duration of Sickness in days (3)	Number of Sickness Claims. (4)	Sickness Rate in days per person-year of exposure (5)	Number of Sickness claims per 100 person-years of exposure (6)
			Males		
15–24	516·9	2,211	105	4·3	20·3
25–34 ..	499 8	3,157	130	6·3	26 0
35–44 .	332 7	1,813	74	5·5	22 2
45–54 .	365·6	3,875	99	10·6	27·1
55–64 ..	194·7	2,263	50	11·6	25·7
65–69 ..	34·8	863	16	24·8	45·9
All Ages .	1,944·5	14,182	474	—	—
Crude Rate .	—	—	—	7·29	24 4
Standardised Rate.	—	—	—	7·24	—
Total number of Weavers = 2,069.					
			Females (Single and Widowed).		
15–24 ..	2,471·2	14,023	542	5·7	21·9
25–34 ..	1,029·9	7,101	235	6·9	22·8
35–44 .	516·3	5,944	163	11·5	31·6
45–54	329 7	4,473	119	13·6	36·1
55–64	127·9	3,136	56	24·5	43·8
65–69	21·7	728	12	33·5	55·2
All Ages	4,496·7	35,405	1,127	—	—
Crude Rate	—	—	—	7·87	25·1
Standardised rate	—	—	—	7·92	—
Total number of weavers = 4,727 and 218 single for part of the year.					
			Females (Married)		
15–24 .	322·4	9,070	267	28·1	82·8
25–34 ..	1,412·9	26,691	768	18·9	54·4
35–44	1,037 6	18,161	512	17·5	49·3
45–54	511·3	10,780	232	21·1	45·4
55–64 .	118·4	2,695	61	22·8	51·5
65–69 .	12·3	730	13	59·4	105·7
All Ages ..	3,415·0	68,127	1,853	—	—
Crude Rate	—	—	—	19·95	54·3
Standardised Rate	—	—	—	19·96	—
Total number of Weavers = 3,631 and 218 married for part of the year.					

The assumption is made that the age distribution *within* the age groups is not dissimilar (or, if so, that the sickness rate is uniform over such a group) and in ten-yearly groups this is not unjustifiable. Comparison of the crude and standardised rates given in Tables II and III shows that the difference between the two is negligible in all cases, or in other words the age distribution in the dry sheds is so similar to that in the wet sheds that standardisation is not really necessary, and no appreciable error will be present in comparing the crude rates. For this reason the claim rate (of which the variation from age to age is not so great) has not been standardised.

Turning to Tables II and III the columns that are vital for the comparison of the wet and dry sheds are numbers (5) and (6). In column (5) is given the number of days of sickness suffered in each group per person-year of exposure in that group ; in column (6) is the number of claims made per 100 person-years of exposure.* The number of claims made is not quite the same as the number of *persons* sick as one person may make more than one claim in the year (each period of incapacity was counted as a separate claim irrespective of whether it was "linked up" or not) The difference will be referred to in a later section.

Comparing, first, the rates found for the males it will be seen that out of the six age groups, five reveal higher sickness rates in the dry sheds. The number of claims in the dry sheds is somewhat smaller in four groups, higher in two groups. Considering the size of the groups it is doubtful whether the differences are significant. Taking all ages, the weavers in the *dry* sheds have nearly one day *more* sickness per year of exposure than those in the wet sheds, while the number of claims is virtually the same in each category.

The females, single and widowed, show the same tendency. The rates in the dry sheds are higher in four age groups than those in the wet sheds. The number of claims is higher in three groups, lower in three groups. For all ages the weavers in the *dry* sheds suffer, approximately, a day and a half *more* sickness than those in the wet sheds. The number of claims is 2 per 100 more.

Finally, the married women in the dry sheds are at a similar disadvantage. They suffer from adverse rates in four groups though their claims are lower in all but one group. For all ages the weavers in the *dry* sheds have nearly one day *more* of sickness than those in the wet sheds, though the number of claims is slightly lower.

* It cannot be expressed "per 100 persons" as the exposure is made up of so many persons exposed for the whole year and so many exposed for only a part. The addition of these two gives "person-years"; in other words, 100 person-years of exposure are the equivalent of 100 persons exposed for one year, though actually they are composed of more than 100 persons exposed for varying durations, some for a whole year and some for less.

It has been pointed out (p. 12) that in the National Health Insurance Acts a distinction is made between "sickness," first 26 weeks of incapacity, and "disablement," incapacity of any duration in excess of 26 weeks, and that in calculating the rates of incapacity suffered this distinction has to be taken into account. Tables II and III, just discussed, relate to the first 26 weeks of sickness only. The amount of "disablement" recorded in this investigation must naturally be very slight, since in a population of persons at work on a specified date and exposed to sickness for one year after that date, the cases of illness lasting for more than half a year, even when the 'linking-up' process is taken into account, must be very limited in number. Actually the "disablement" recorded is too small in total to be of any importance, and a comparison of its incidence in the humid and non-humid sheds would be of no value. It has, therefore, been considered a better procedure not to set out the "disablement" separately, but to combine it with the sickness into one rate—an "incapacity rate."* Such rates are given in Table III A, and it will be observed that they place, as did the "sickness" rates in the previous tables, the non-humid sheds in a slightly adverse position in all cases, men, single women, and married women.

TABLE IIIA.—*The total incapacity (sickness rate plus disablement rate) recorded in total of Non-Humid and Humid Sheds in All Towns.*

Age Group (age last birthday).	Incapacity Rate in days per person-year of exposure	
	Non-Humid	Humid
Males—		
15–24	5·5	4·3
25–34	8·5	6·6
35–44	9·1	5·6
45–54	11·1	13·0
55–64	14·8	13·4
65–69	35·4	28·8
All Ages—Crude Rate	9·39	8·13
Standardised Rate	9·43	8·05
Females (Single and Widowed)—		
15–24	8·0	6·0
25–34	10·1	7·5
35–44	15·9	12·4
45–54	13·9	13·9
55–64	23·0	33·6
65–69	49·1	37·4
All Ages—Crude Rate	10·62	8·62
Standardised Rate	10·55	8·70
Females (Married)—		
15–24	24·9	30·8
25–34	22·9	21·2
35–44	22·2	20·3
45–54	28·1	25·4
55–64	22·1	31·0
65–69	120·9	87·0
All Ages—Crude Rate	24·00	23·07
Standardised Rate	23·99	23·08

* The "sickness" (first 26 weeks) is kept separate in the main tables so that comparison of the incidence may be made with that found in other industries, if so desired

If the same population could, by any means, be studied over a considerable number of years the "disablement" would, obviously, assume larger proportions and comparison of its incidence in the two environments might then be effected. In practice this is impossible, as the labour turnover is far too large This inquiry was, therefore, confined to one year, and the answer to the problem set—does artificial humidification have a deleterious effect upon health—is given by a comparison of incapacity of duration less than one year.

A further comparison of some of the same figures as in Tables II and III is given in a different form in Table IV. This shows the average number of days absence caused through each sickness claim, in the different age groups in the wet and dry sheds. It is the total duration of sickness experienced, from column (3) of Tables II and III, divided by the number of claims made, given in column (4). Tables II and III give the days of sickness suffered *per person-year of exposure*; Table IV gives the days of sickness suffered per *claim* made *

TABLE IV.—*Number of Days of Sickness (i e., first 26 weeks) per Claim* in the Non-Humid and Humid Sheds in All Towns*

Age Group (age last birthday)	Number of Days of Sickness per Claim					
	Males.		Females (Single and Widowed).		Females (Married).	
	Non-Humid.	Humid	Non-Humid.	Humid	Non-Humid	Humid.
15-24	26·6	21·1	28·3	25·9	36·8	34·0
25–34	27·4	24·3	35·0	30·2	37 9	34·8
35–44	34·1	24·5	45·7	36·5	39·1	35·5
45–54	39·1	39·1	39·4	37·6	46·2	46·5
55–64	48·5	45·3	45·8	56 0	41·9	44·2
65–69 . ..	86·6	53·9	83·4	60·7	64·4	56·2
All Ages, Crude Rate	34·4	29·9	34·5	31·4	39·6	36·8

* Each period of sickness was counted as a claim irrespective of whether it was "linked-up" or not.

In fourteen of the eighteen groups the duration of sickness per claim is higher in the non-humid sheds, in one group it equals that found in the humid sheds, and in only three does it fall below the humid rate. This result must obviously arise, for it has

* A claim is here defined as a period of sickness, quite irrespective of whether that period was linked up with a previous period or not. In the paper by the Government Actuary previously cited (p 10), the procedure was the reverse—a series of linked-up periods was counted as only one claim

already been shown in Tables II and III that the *amount* of sickness is somewhat greater in the dry sheds than in the wet, while the *number* of claims is, approximately, the same under both environments. In other words, the slight excess of sickness found under non-humid conditions does not arise from an excess of claims, but from longer duration of sickness when contracted It will be seen later, in Table VI that this longer duration of sickness is due to the presence of a few more claims of very long duration in the non-humid sheds and not to any uniform difference in the two groups.

A further comparison that it will be of value to make relates to the number of *persons* falling sick under the humid and non-humid conditions. In Tables II and III is given the number of *claims* made, but one person may make two or more claims in the same year, and thus there is a difference between the number of claims made and the number of persons falling sick Table V shows, in the form of percentages, the proportion of persons under each environment who had no sickness, one sickness, two sicknesses, and so on during the year of inquiry. These figures, it must be observed, do not relate to the same population as that in the former tables. They are calculated only upon weavers who were exposed in the same group for the *whole year*, i.e., all exits and all women married during the year and transferred from the single to the married group are excluded These two groups cannot be included, for, without making some arbitrary assumption, it is not known how many sicknesses they would have suffered if their exposure had continued for the whole year.* The percentages are, therefore, calculated on a total population of somewhat over 16,000, which was exposed throughout the whole year of investigation. The rates given are crude rates ; standardisation, as has already been seen, makes only a negligible difference. The table refers to sickness in the technical sense, i e., disablement claims were not included.

The differences revealed are again negligible. The proportion of males who suffered from sickness during the year is nearly identical in the two types of mills. Slightly more single women were sick in the dry sheds, slightly more married women in the wet, but the difference in neither case is large enough to suggest significance. The analysis of repeated sicknesses shows very similar results, and a lack of significant differences. It proves that the comparative rates found in Tables II and III are not based upon different distributions of persons suffering from more than one period of incapacity.

A final comparison is given in Table VI, in which the durations of sickness experienced are given in a different form.† The Table

* As the great majority of exits was due to trade conditions and relatively few to illness, there is no reason to believe that their exclusion gives any significant bias.

† This again relates only to weavers whose sickness history could be used for the whole year.

shows, as a percentage of the total claims, the number of claims which were of duration 1 to 14 days, 15 to 28 days, and so on. For instance, in the non-humid sheds for the males 42·1 per cent. of the sickness claims were of duration between 1 and 14 days, 22·2 per cent. were of duration between 15 and 28 days, 13·5 per cent. were of duration between 29 and 42 days.

TABLE V.—*Number of Persons exposed for the whole year who suffered from no sickness or from one or more sicknesses (disablement cases not included) during the year of investigation (expressed as per cent. of total population in each group), in Non-Humid and Humid Sheds in All Towns.*

	Percentage suffering from						
	No Sickness *	One or more Sicknesses.	1 Sicknesses.	2 Sicknesses.	3 Sicknesses.	4 Sicknesses.	5 Sicknesses.
Non-Humid Sheds—							
Males..	80·9	19·1	16·1	2·3	0·7	0·1	—
Females (single and widowed)	78·4	21·6	17·7	3·2	0·7	0·03	—
Females (married) ..	61·4	38·6	29·0	7·7	1·5	0·2	0·1
Humid Sheds—							
Males..	80·7	19·3	15·8	2·8	0·7	0·1	—
Females (single and widowed)	79·2	20·8	17·4	2·9	0·3	0·1	—
Females (married) ..	60·7	39·3	29·3	8·1	1·5	0·3	0·1

* The Table reads: Of all the males exposed for the whole year in the non-humid sheds, 80·9 per cent. had no sickness during the year, 19·1 per cent. had one or more periods of sickness, 16·1 per cent were sick once, 2·3 per cent. were sick twice, 0·7 per cent were sick three times, and 0·1 per cent. were sick four times.

In comparing the two groups only two material differences are to be seen. (1) In the wet sheds there were more claims, made by males, of duration 15 to 28 days, and consequently fewer claims in the other groups. (2) For males and both single and married women there were more claims of very long duration, i.e., over 84 days (or 12 weeks) in the non-humid sheds. If the table be divided into two groups only, sicknesses under 2 months' duration and sicknesses over 2 months' duration (i.e. 56 days), the result, as shown in Table VI reveals a slight excess of sicknesses of shorter duration in the humid mills and a corresponding excess of longer sicknesses in the non-humid mills. The difference is the same for each of the "sex" groups, which suggests that it may be significant. On the other hand, in each case it is a very small difference. It can, therefore, scarcely be held to be valid evidence of a

real excess of sicknesses of short duration in the wet sheds any more than it can be argued that the dry environment is conducive to longer periods of incapacity.

TABLE VI.—*Number of Sickness Claims (Disablement Claims not included) of given durations, expressed as a percentage of total number of claims. For persons exposed for the whole year of inquiry. Non-Humid and Humid Sheds in All Towns.*

Duration of Sickness in Days.	Percentage of all Sicknesses falling in each group.					
	Males.		Females (Single and Widowed).		Females (Married).	
	Non-Humid.	Humid	Non-Humid.	Humid.	Non-Humid.	Humid.
1–14 . . .	42·1*	41·5	32·5	32·4	24·2	26·4
15–28	22·2	29·6	30·3	31·5	29·0	29·1
29–42	13·5	10·7	14·1	14·2	16·6	16·2
43–56	5·4	5·8	8·7	8·2	9·6	10·5
57–70	4·7	3·0	3·0	4·9	5·6	6·3
71–84	2·1	2·8	2·6	2·9	5·0	3·8
Over 84 . .	10·0	6·5	8·7	6·0	10·1	7·6
1–56	83·2	87·6	85·6	86·3	79·4	82·2
Over 56 . .	16·8	12·3	14·3	13·8	20·7	17·7

* The Table reads: Of all the males who suffered from sickness during the year in the non-humid sheds, 42·1 per cent. were ill for 1 to 14 days, 22·2 per cent. were ill for 15 to 28 days, 13·5 per cent were ill for 29 to 42 days. Of those who were ill in the humid sheds 41·5 per cent. were ill for 1 to 14 days, etc

The only large difference to be seen is that for males, duration 15 to 28 days. Whether this is a significant difference it is difficult to say, but the figures for the women do not confirm it.† A similar analysis for each town showed that this result for "all towns" is mainly due to the figures for Burnley. Preston, too, gives percentages of the same form, but the figures upon which they are based are too small to be taken as reliable evidence. Nelson and Blackburn, on the other hand, give an identical figure in this group—22 per cent. of the sicknesses of males in each case are of duration 15 to 28 days. In Accrington the figures are negligible. No reason suggests itself as to why such sicknesses should be more common for males in the wet sheds than in the dry, while for the following group, 29 to 42 days, the reverse should occur.

The greater number of longer sicknesses found here under the non-humid conditions is the explanation of the excess of sickness already found in these sheds (vide Tables II, III, and IV).

† If the ordinary formula for testing the significance of a difference of proportions be used the probable error is given as $\pm$ 1·89, which makes the difference just significant.

As these claims, although they contribute a large *duration* of sickness, form a relatively small proportion of the whole number of claims, the significance of the difference in incidence between the two types of sheds is thrown still more into doubt.

If it be conceded, as seems reasonable, that all the slight differences thus found between the wet and dry sheds are too small to be significant, then the conclusion from this initial summary must be that a year's investigation gives no evidence to warrant the belief that the environment in the humid shed is more detrimental to health than that of the non-humid shed. But before accepting such a conclusion comparison must first be made of the rates found to exist in the different towns.

Comparison of the Sickness Incidence in the Humid and Non-Humid Sheds within each of the Five Towns investigated.

In Tables VII to XIV are set out the numbers exposed to risk and the details relating to the sickness suffered for each of the five towns included in the inquiry, in decennial age-groups, and the crude and standardised rates for all ages. It will be observed that the exposed to risk (column 2 of the Tables) in some of the age-groups is very small, and consequently very little stress can be laid upon variations in individual groups. Each group taken alone is too liable to the random fluctuations due to insufficient numbers. Attention must mainly be paid to the extent to which any difference found is consistent over all the age-groups. The standardised rate summarises this information. Owing to this smallness of numbers in the age-groups the claim rate per 100 person-years of exposure has been calculated only for all ages, and is given as a crude rate, as standardisation has had little effect on any of the sickness rates.

Tables VI and VII give the comparison of the sickness found in the humid and non-humid sheds in Preston. For males th sickness rate (column 5) is greater in the humid sheds in three of the age-groups and smaller in three. Using the standardised rate for all ages as a measure, the weavers in the humid sheds have, on the average, just over three-quarters of a day more sickness per year. Their claims are 5 per 100 more The numbers exposed to risk on which these figures are based are less than 300 in each case, and it would be unwise to argue that such a small difference was significant.

The single females in Preston are, on the other hand, found to be in an adverse position in the non-humid sheds. In four of the groups the sickness rate is higher in those sheds, while the standardised rate gives an average of nearly two days more sickness per weaver under the non-humid conditions. There is no real significant difference in the claim rate, which appears one per 100 higher in the non-humid sheds

The married women give a similar result. The non-humid sheds have, in comparison with the humid, adverse rates in five of the groups (though the age-group 65–69 may be dismissed as

being too small to have any meaning whatever), and a standardised rate shows nearly two days' sickness more per year of exposure than that found in the wet sheds. The claim rate is very slightly higher in the humid sheds but not significantly so.

Turning to Tables IX and X, analysis of the rates found to prevail in Burnley gives the following results. The men suffer from higher sickness rates in the humid sheds in three groups, while in the other three groups the non-humid sheds are at a disadvantage. The standardised rate reveals substantially the same position under each environment, while the claim rates are identical. The position of the single women, as judged by the rates in the age-groups, is somewhat worse in the humid sheds, which have higher sickness in four out of the six groups. But in the two youngest groups (containing the largest numbers exposed) the non-humid sheds are at a disadvantage, the result being shown in the standardised rate, which is one day higher in the dry sheds The claim rate is 5 more per 100 years of exposure. The standardised rates for the married women are identical, though there are slightly more claims under the humid conditions In the age-groups four rates are higher in the humid sheds

In Accrington (Tables XI and XII) the exposure is very small in the non-humid sheds, and care must be exercised in making comparison. For the males the sickness is only 0·72 days per year of exposure (standardised rate) in the non-humid sheds, as compared with 5·26 days in the humid sheds, but any discussion of such a result would be absurd in view of the fact that the total exposure to risk in the dry sheds was only 21·7 person-years. The number of women exposed, both single and married, was also very limited (the closing of mills in Accrington referred to before, p. 9, was partially responsible for this), and comparison of the age groups is scarcely justifiable. The standardised rates suggest that the single and married women both suffer more sickness in the non-humid sheds. The single women have only half a day's more sickness, but their claim-rate is 4 per 100 higher. The married women have five more days' sickness per weaver and 5 more claims per 100.

There remain, finally, the two homogeneous towns—Nelson entirely non-humid, Blackburn entirely humid. If comparison be made between the two it is seen that the males and single females are at a disadvantage in the non-humid town, while, on the other hand, the married women there suffer less incapacity. For the men the rates are higher in Nelson in all the groups, and the standardised rate gives that town two days' more sickness per male weaver, but there is no difference in the claim-rate

The single women have higher rates in four groups in Nelson, and their standardised rate is one day higher, although the claim-rate is somewhat lower.

The married women show distinctly lower rates in Nelson for sickness and claims for all age-groups.

Table VII.—*Sickness (first 26 weeks) recorded in Non-Humid Sheds in Preston.*

Age Group (age last birthday). (1)	Person-years of exposure for Sickness. (2)	Total Duration of Sickness in days. (3)	Number of Sickness Claims. (4)	Sickness Rate in days per person-year of exposure. (5)	Number of Sickness Claims per 100 person-years of exposure. (6)
		Males.			
15–24 ..	58·0	112	6	1·9	—
25–34 ..	72·4	480	11	6·6	—
35–44 ..	46·6	423	7	9·1	—
45–54 ..	49·4	231	5	4·7	—
55–64 ..	33·2	199	3	6·0	—
65–69 ..	11·7	156	4	13·3	—
All Ages ..	271·4	1,601	36	—	—
Crude Rate	—	—	—	5·90	13·3
Standardised Rate	—	—	—	5·47	—
		Females (Single and Widowed).			
15–24 ..	443·9	3,238	91	7·3	—
25–34 ..	275·9	2,240	59	8·1	—
35–44 ..	160·5	2,347	46	14·6	—
45–54 ..	92·6	1,212	29	13·1	—
55–64 ..	40·9	871	11	21·3	—
65–69 ..	7·8	309	3	39·6	—
All Ages ..	1,020·9	10,217	239	—	—
Crude Rate..	—	—	—	10·01	23·4
Standardised Rate	—	—	—	9·36	—
		Females (Married).			
15–24 ..	47·2	1,167	32	24·7	—
25–34 ..	252·9	4,700	112	18·6	—
35–44 ..	183·2	3,222	77	17·6	—
45–54 ..	90·1	1,983	38	22·0	—
55–64 ..	20·1	436	10	21·7	—
65–69 ..	2·0	214	2	107·0	—
All Ages ..	595·4	11,722	271	—	—
Crude Rate..	—	—	—	19·69	45·5
Standardised Rate	—	—	—	19·81	—

TABLE VIII.—*Sickness (first 26 weeks) recorded in Humid Sheds in Preston.*

Age Group (age last birthday) (1)	Person-years of exposure for Sickness (2)	Total Duration of Sickness in days (3)	Number of Sickness Claims (4)	Sickness Rate in days per person-year of exposure. (5)	Number of Sickness Claims per 100 person years of exposure. (6)
		Males.			
15–24	74·5	429	11	5·8	—
25–34 .	83·9	195	8	2·3	—
35–44 .	45·4	331	12	7·3	—
45–54	57·6	638	15	11·1	—
55–64 ..	22·1	158	5	7·2	—
65–69 ..	5·0	53	2	10·6	—
All Ages .	288·4	1,804	53	—	—
Crude Rate	—	—	—	6·26	18·4
Standardised Rate	—	—	—	6·28	—
		Females (Single and Widowed).			
15–24 ..	858·5	5,092	182	5·9	—
25–34 ..	344·8	2,173	62	6·3	—
35–44 ..	186·5	1,319	38	7·1	—
45–54 ..	119·0	2,057	45	17·3	—
55–64 ..	45·8	979	16	21·4	—
65–69 ..	9·0	106	2	11·8	—
All Ages ..	1,563·7	11,726	345	—	—
Crude Rate	—	—	—	7·50	22·1
Standardised Rate	—	—	—	7·45	—
		Females (Married).			
15–24 ..	111·8	3,021	82	27·0	—
25–34 ..	464·6	8,034	218	17·3	—
35–44 ..	323·7	4,868	132	15·0	—
45–54 ..	145·4	2,694	49	18·5	—
55–64 ..	43·7	945	21	21·6	—
65–69 ..	2·0	46	1	23·0	—
All Ages ..	1,091·2	19,608	503	—	—
Crude Rate ..	—	—	—	17·97	46·1
Standardised Rate	—	—	—	17·89	—

TABLE IX.—*Sickness (first 26 weeks) recorded in Non-Humid Sheds in Burnley*

Age Group (age last birthday). (1)	Person-years of exposure for Sickness. (2)	Total Duration of Sickness in days (3)	Number of Sickness Claims. (4)	Sickness Rate in days per person-year of exposure. (5)	Number of Sickness Claims per 100 person-years of exposure. (6)
		Males			
15–24 ..	315·3	2,005	75	6·4	—
25–34 ..	315·7	2,301	84	7·3	—
35–44 ..	182·0	1,091	46	6·0	—
45–54 ..	178·9	1,546	51	8·6	—
55–64 ..	110·1	1,440	38	13·1	—
65–69 ..	17·0	515	5	30·3	—
All Ages ..	1,118·9	8,898	299	—	—
Crude Rate	—	—	—	7·95	26·7
Standardised Rate	—	—	—	8·05	—
		Females (Single and Widowed).			
15–24 ..	758·9	6,060	225	8·0	—
25–34 ..	300·0	2,903	95	9·7	—
35–44 ..	134·9	1,851	46	13·7	—
45–54 ..	82·4	871	22	10·6	—
55–64 ..	42·6	862	29	20·2	—
65–69 ..	6·3	327	3	51·6	—
All Ages ..	1,325·1	12,874	420	—	—
Crude Rate..	—	—	—	9·72	31·7
Standardised Rate	—	—	—	9·83	—
		Females (Married).			
15–24 ..	106·4	2,788	81	26·2	—
25–34 ..	406·4	9,108	252	22·4	—
35–44 .	384·6	8,629	224	22·4	—
45–54 ..	178·9	4,375	99	24·5	—
55–64 ..	39·1	579	19	14·8	—
65–69 ..	6·3	360	6	56·7	—
All Ages ..	1,121·7	25,839	681	—	—
Crude Rate..	—	—	—	23·04	60·7
Standardised Rate	—	—	—	22·96	—

TABLE X.—*Sickness (first 26 weeks) recorded in Humid Sheds in Burnley.*

Age Group (age last birthday). (1)	Person-years of exposure for Sickness. (2)	Total Duration of Sickness in days (3)	Number of Sickness Claims. (4)	Sickness Rate in days per person-year of exposure. (5)	Number of Sickness Claims per 100 person-years of exposure. (6)
			Males.		
15–24 ..	315·5	1,162	66	3·7	—
25–34 ..	291·1	2,229	94	7·7	—
35–44 ..	207·8	837	42	4·0	—
45–54 ..	194·8	2,513	62	12·9	—
55–64 ..	94·3	1,527	30	16·2	—
65–69 ..	9·4	93	4	9·9	—
All Ages .	1,113·0	8,361	298	—	—
Crude Rate..	—	—	—	7·51	26·8
Standardised Rate	—	—	—	7·79	—
			Females (Single and Widowed).		
15–24 ..	653·8	3,692	144	5·6	—
25–34 ..	278·7	1,807	71	6·5	—
35–44 .	106·5	1,626	48	15·3	—
45–54 ..	57·5	664	19	11·5	—
55–64 .	23·0	922	18	40·1	—
65–69 ..	3·4	226	2	66 0	—
All Ages ..	1,122·9	8,937	302	—	—
Crude Rate..	—	—	—	7·96	26·9
Standardised Rate.	—	—	—	8·75	—
			Females (Married)		
15–24 ..	107·0	3,280	103	30·6	—
25–34 ..	408·4	9,274	251	22·7	—
35–44 ..	258·9	4,998	152	19·3	—
45–54 ..	176·5	3,924	98	22·2	—
55–64 ..	34·9	1,163	24	33·4	—
65–69 ..	1·0	185	1	185·0	—
All Ages ..	986·7	22,824	629	—	—
Crude Rate..	—	—	—	23·13	63·7
Standardised Rate	—	—	—	23·31	—

TABLE XI.—*Sickness (first 26 weeks) recorded in Non-Humid Sheds in Accrington.*

Age Group (age last birthday). (1)	Person-years of exposure for Sickness. (2)	Total Duration of Sickness in days (3)	Number of Sickness Claims. (4)	Sickness Rate in days per person-year of exposure. (5)	Number of Sickness Claims per 100 person-years of exposure. (6)
		Males			
15–24 ..	1·7	—	—	—	—
25–34 ..	5·5	—	—	—	—
35–44 ..	2·0	—	—	—	—
45–54 ..	4·4	10	1	2·3	—
55–64 ..	6·2	20	1	3·2	—
65–69 ..	1·8	—	—	—	—
All Ages ..	21·7	30	2	—	—
Crude Rate..	—	—	—	1·39	9·2
Standardised Rate	—	—	—	0·72	—
		Females (Single and Widowed).			
15–24 ..	159·1	1,066	41	6·7	—
25–34 ..	61·9	606	17	9·8	—
35–44 ..	38·0	245	11	6·5	—
45–54 ..	26·1	375	11	14·4	—
55–64 .	14·5	352	10	24·2	—
65–69 ..	1·9	14	1	7·5	—
All Ages ..	301·4	2,658	91	—	—
Crude Rate .	—	—	—	8·82	30·2
Standardised Rate	—	—	—	8·48	—
		Females (Married).			
15–24 ..	23·9	585	15	24·5	—
25–34 ..	87·7	2,135	61	24·4	—
35–44 ..	69·6	1,225	31	17·6	—
45–54 ..	31·1	710	18	22·8	—
55–64 ..	10·5	443	5	42·3	—
65–69 ..	—	—	—	—	—
All Ages ..	222·7	5,098	130	—	—
Crude Rate..	—	—	—	22·89	58·4
Standardised Rate	—	—	—	22·56	—

TABLE XII.—*Sickness (first 26 weeks) recorded in Humid Sheds in Accrington.*

Age Group (age last birthday). (1)	Person-years of exposure for Sickness. (2)	Total Duration of Sickness in days. (3)	Number of Sickness Claims (4)	Sickness Rate in days per person-year of exposure. (5)	Number of Sickness Claims per 100 person-years of exposure. (6)
		Males.			
15–24 ..	15·2	98	6	6·4	—
25–34 ..	19·8	73	3	3·7	—
35–44 .	9·6	83	3	8·6	—
45–54 .	27·7	38	2	1·4	—
55–64 ..	14·7	36	2	2·4	—
65–69 ..	5·0	166	2	33·2	—
All Ages ..	92·1	494	18	—	—
Crude Rate ..	—	—	—	5·36	19·5
Standardised Rate	—	—	—	5·26	—
		Females (Single and Widowed).			
15–24 ..	546·9	3,231	127	5·9	—
25–34 ..	221 2	1,455	59	6·6	—
35–44 ..	108·9	1,404	37	12·9	—
45–54 .	59·4	494	16	8·3	—
55–64 ..	21·7	553	7	25·4	—
65–69 ..	3·0	178	3	59·3	—
All Ages ..	961·1	7,315	249	—	—
Crude Rate..	—	—	—	7·61	25·9
Standardised Rate	—	—	—	7·93	—
		Females (Married).			
15–24 ..	56·1	1,165	38	20·8	—
25–34 ..	272·8	4,348	150	15·9	—
35–44 ..	218·1	4,050	113	18·6	—
45–54 ..	73·9	1,165	26	15·8	—
55–64 ..	10·5	218	6	20·8	—
65–69 ..	1·0	84	3	84·0	—
All Ages ..	632·3	11,030	336	—	—
Crude Rate..	—	—	—	17·45	53·1
Standardised Rate	—	—	—	17·61	—

TABLE XIII.—*Sickness (first 26 weeks) recorded in Nelson. All Non-Humid Sheds.*

Age Group (age last birthday). (1)	Person-years of exposure for Sickness. (2)	Total Duration of Sickness in days. (3)	Number of Sickness Claims. (4)	Sickness Rate in days per person-year of exposure (5)	Number of Sickness Claims per 100 person-years of exposure. (6)
		Males.			
15–24 ..	364·8	1,738	64	4·8	—
25–34 ..	323·8	2,260	89	7·0	—
35–44 ..	208·8	1,862	46	8·9	—
45–54 ..	218·0	2,514	53	11·5	—
55–64 ..	115·6	1,980	33	17·1	—
65–69 ..	18·0	802	8	44·6	—
All Ages ..	1,249·0	11,156	293	—	—
Crude Rate..	—	—	—	8·93	23·5
Standardised Rate	—	—	—	9·20	—
		Females (Single and Widowed).			
15–24 ..	498·7	3,112	120	6·2	—
25–34 ..	204·0	1,710	42	8·4	—
35–44 ..	94·1	1,408	25	15·0	—
45–54 ..	30·9	459	12	14·8	—
55–64 ..	20·0	569	8	28·5	—
65–69 ..	2·1	17	1	8·0	—
All Ages ..	849·8	7,275	208	—	—
Crude Rate..	—	—	—	8·56	24·5
Standardised Rate	—	—	—	9·07	—
		Females (Married).			
15–24 ..	71·3	1,492	36	20·9	—
25–34 ..	244·2	3,966	100	16·2	—
35–44 ..	149·5	1,974	53	13·2	—
45–54 ..	64·6	1,346	27	20·8	—
55–64 ..	10·1	93	3	9·2	—
65–69 ..	1·1	6	1	5·4	—
All Ages ..	540·7	8,877	220	—	—
Crude Rate	—	—	—	16·42	40·7
Standardised Rate	—	—	—	16·17	—

TABLE XIV.—*Sickness (first 26 weeks) recorded in Blackburn. All Humid Sheds.*

Age Group (age last birthday) (1)	Person-years of exposure for Sickness. (2)	Total Duration of Sickness in days. (3)	Number of Sickness Claims (4)	Sickness Rate in days per person-year of exposure (5)	Number of Sickness Claims per 100 person-years of exposure. (6)
		Males			
15–24 ..	111·7	522	22	4·7	—
25–34 .	104·9	660	25	6 3	—
35–44 ..	69 8	562	17	8·1	—
45–54 ..	85·6	686	20	8·0	—
55–64 ..	63·5	542	13	8·5	—
65–69 .	15 5	551	8	35·6	—
All Ages ..	451·0	3,523	105	—	—
Crude Rate.	—	—	—	7·81	23·3
Standardised Rate	—	—	—	7 21	—
		Females (Single and Widowed).			
15–24 ..	412·0	2,008	89	4·9	—
25–34 ..	185·2	1,666	43	9·0	—
35–44 ..	114·4	1,595	40	13·9	—
45–54 ..	93·7	1,258	39	13·4	—
55–64 .	37·3	682	15	18·3	—
65–69	6·3	218	5	34·5	—
All Ages ..	849·0	7,427	231	—	—
Crude Rate..	—	—	—	8·75	27·2
Standardised Rate	—	—	—	8·07	—
		Females (Married)			
15–24 ..	47·5	1,604	44	33·7	—
25–34 ..	267·1	5,035	149	18·9	—
35–44 ..	237·0	4,245	115	17·9	—
45–54 ..	115·5	2,998	59	26·0	—
55–64 .	29·4	369	10	12·6	—
65–69 .	8·3	415	8	50·0	—
All Ages ..	704·8	14,666	385	—	—
Crude Rate .	—	—	—	20·81	54·6
Standardised Rate	—	—	—	20·96	—

Summing up the information thus obtained for each town the following results are reached :—(1) Males : In Preston the workers in the wet sheds are at a very slight disadvantage. In Burnley no significant difference is found between the two groups. In Accrington the figures are too small to allow comparison. In Nelson, all dry sheds, the rates are higher than those found in Blackburn, all wet sheds. (2) Females, single and widowed : The weavers in the dry sheds suffer from somewhat higher rates in Preston, Burnley, and Accrington, while Nelson, all dry sheds, has a higher rate than that of Blackburn, all wet sheds. (3) Females, married : In Preston the weavers in the dry sheds are at a small disadvantage. In Burnley no difference exists between the two types of sheds. In Accrington the rate is substantially higher in the dry sheds, but the small number exposed to risk does not justify assumption of its significance. In Nelson, all dry sheds, the rate is substantially lower than in Blackburn, all wet sheds. This is the sole group in which the contention that humidity causes high sickness rates is at all borne out, and as this involves comparison of two towns it cannot, for reasons previously indicated, command very great confidence. It is possible that some other factor may be present ; for instance, in analysing sickness by cause a contributory factor was found in the difference in the sickness rates in the two towns due to illnesses arising from pregnancy. In Blackburn the number of such claims per 100 years of exposure was 5·82 ; in Nelson it was only 2·03. The number of days of such sickness per year of exposure was in Blackburn 2·77, in Nelson 1·41.

In Table XIVA the small amount of disablement recorded has been included (as in Table IIIA for all towns taken together) and a total "incapacity rate" is thus given for each town and environmental category. The inclusion of disablement does not materially alter the comparative values of the rates, and the figures given in Table XIVA give rise to substantially the same conclusions as have just been given in the preceding summary.

The same analysis has been carried out as was made for all the towns taken together (vide Table IV) and in Table XV the number of days lost through each sickness claim is given separately for each town and for each category. The calculation has been made for all ages only. It has already been seen that the numbers in the ten-year age-groups are too small to afford any very consistent results so that no real purpose would be gained by calculating this constant for each age-group. The rate given is the crude rate (Tables VII to XIV prove that standardisation makes no material difference). Taking this Table as it stands, in Accrington only, and then only for the males, was the time lost per sickness claim at a higher level in the humid sheds, and in this town the figure for the males in the dry sheds is valueless owing to the paucity of numbers exposed to risk. In all other groups the non-humid population appears at a disadvantage.

TABLE XIVA.—*The total incapacity (sickness rate plus disablement rate) recorded in Non-Humid and Humid Sheds in each town investigated.*

Town.	Incapacity Rate in days per person-year of exposure. Standardised Rate.		
	Males.	Females (single and widowed)	Females (married)
Preston—			
Non-Humid . ..	5·62	9·90	21·97
Humid	6·28	8·05	20 16
Burnley—			
Non-Humid .. .	9·39	11·21	27·17
Humid .	9·05	9·78	28·64
Accrington—			
Non-Humid	0·72	9·43	27·14
Humid	5·26	8·65	18·79
Nelson—			
Non-Humid	10·63	10·72	18·13
Blackburn—			
Humid	7·74	8·90	24·15

TABLE XV.—*Number of Days of Sickness (i e., first 26 weeks) per Claim.* Crude Rate for all ages. In Non-Humid and Humid Sheds in each town investigated.*

Town	Number of Days of Sickness per Claim in	
	Non-Humid Sheds.	Humid Sheds.
Preston—		
Males	44·5	34·0
Females (single and widowed) .	42·7	34·0
Females (married)	43·3	39·0
Burnley—		
Males	29·8	28·1
Females (single and widowed) .	30·7	29·6
Females (married)	37·9	36·3
Accrington—		
Males	15·0	27·4
Females (single and widowed) ..	29·2	29·4
Females (married)	39·2	32·8
Nelson—		
Males	38·1	—
Females (single and widowed) ..	35·0	—
Females (married)	40·4	—
Blackburn—		
Males	—	33·6
Females (single and widowed) .	—	32·2
Females (married)	—	38·1

* Each period of sickness was counted as a claim irrespective of whether it was "linked-up" or not.

In Preston the differences are large and appear significant. In Burnley they are consistent over the three groups but are so small that no great weight attaches to them. Nelson shows a longer duration of sickness per claim in each group than Blackburn and the differences are large enough to suggest significance.

If this Table be read in conjunction with Tables VII to XIV the following conclusions may be drawn.

Preston.

Males.—The rate of sickness suffered is slightly higher in the humid sheds; in the humid sheds the number of claims is higher but in the non-humid sheds the average duration of each claim is longer.

Single Females.—The sickness rate, the claim rate and the average duration of sickness per claim are all higher in the non-humid sheds.

Married Females.—The sickness rate and the duration of claim are higher in the non-humid sheds. The claim rate is approximately the same in either shed.

Burnley

Males.—The sickness rate, the claim rate, and the average duration of sickness per claim do not differ significantly between the wet and dry mills.

Single Females.—The sickness rate and the duration of sickness are a little higher while the claim rate is significantly higher in the dry sheds.

Married Females.—The sickness rates are alike, the claim rate is higher in the humid sheds, but the non-humid sheds have a slightly longer duration for each claim made.

Accrington.

Males.—The smallness of numbers makes comparison valueless.

Single Females.—The sickness rates are alike, there are considerably more claims in the non-humid sheds, but the duration of each claim is identical with that arising from the humid environment.

Married Females.—All the rates are higher under the non-humid conditions.

Blackburn and Nelson.

Males.—Nelson, the "dry town," has a higher sickness rate, and a longer duration for each sickness; the number of claims made is the same in each town.

Single Females.—The sickness rate and duration of sickness are a little higher in Nelson, but a few more claims are made in Blackburn.

Married Females.—The sickness rate and claim rate are lower in Nelson, but the duration of each claim is slightly higher there than in Blackburn.

Thus for each town the final result reached is similar to that already found for all the towns taken together, i.e., there is no evidence of a higher sickness incidence in the humid sheds. Indeed, on the whole, there is a suggestion in the figures to the contrary, that the workers in the non-humid mills are at a slight disadvantage.

A final comparison is given in Table XVI which shows the proportion of persons in each town and in each environment who suffered from no sickness or from one or more sicknesses (disablement claims not included).* Again no consistent and significant difference is revealed between the incidences in the two groups of mills. In four cases the proportion of persons suffering from sickness is greater in the humid sheds; in three cases it is greater in the non-humid sheds; in four cases it is practically identical for both sheds. In addition there is no evidence that the difference in environment is producing any variation worthy of attention in the distributions of persons suffering from more than one period of sickness.

In the comparison of Nelson and Blackburn it has been seen that the dry sheds of the former town have for males and single women somewhat more unfavourable rates than the wet sheds of the latter. On the other hand, the married women are at a distinct disadvantage in Blackburn. In comparing the two towns some attention ought to be paid to their vital statistics. These may indicate more unfavourable conditions in one or other of the towns to the exclusion of the humidity factor.

The town of Nelson is considerably smaller and more modern than Blackburn. In 1921 it had a population of 40,690, against 126,643 in Blackburn. Its standardised death-rate for 1925 was 13·0 per 1,000, while in Blackburn, for the same year, it was 14·3 per 1,000. In both towns the chief industry is cotton weaving. The number of persons per house, according to the 1921 census, is the same, 4·1 per house. The Medical Officer of Health for Nelson states in his 1925 report that the housing accommodation is of a very good type, very few back-to-back houses, and no slum area in the district. In Blackburn there are, according to the Medical Officer, " areas which come near to the border line between the average and the slum, but it cannot be said that there is any real slum property."† In both cases there have been fluctuations in the staple trade, and severe periods of depression since the war.

The only suggestion that can be gained from these factors is that since Blackburn has a slightly higher death-rate it might be expected to suffer from at least as high a sickness rate as Nelson. Actually this was not so for the males and single women, though for the married women Blackburn was certainly at a disadvantage.

* This is calculated, as for the " all-towns group," only for the weavers exposed for the whole year of investigation

† Annual Report upon the Health of Blackburn, 1925, by D. M. Holden, M.D., D.P.H., Medical Officer of Health. p. 181.

TABLE XVI.—*Number of Persons exposed for the whole year who suffered from no sickness or from one or more sicknesses (disablement cases not included) during the year of investigation (expressed as per cent. of total population in each group), in Non-Humid and Humid Sheds in each Town.*

Town and Group.		Per cent of Total Population suffering from—						
		No Sickness.*	One or more Sicknesses	One Sickness.	Two Sicknesses	Three Sicknesses.	Four Sicknesses.	Five Sicknesses.
Preston—								
Males	Non-Humid	89·8	10·2	9·0	0·8	0·4	—	—
	Humid	84·4	15·6	13·3	1·9	0·4	—	—
Single Females	Non-Humid	80·4	19·6	17·2	2·2	0·2	—	—
	Humid	81·7	18·3	15·9	2·2	0·1	0·07	—
Married Females	Non-Humid	65·5	34·5	26·9	6·0	1·6	—	—
	Humid	65·4	34·6	27·9	5·7	0·8	0·2	—
Burnley—								
Males	Non-Humid	77·8	22·2	18·8	2·5	0·7	0·2	—
	Humid	78·4	21·6	17·7	3·2	0·7	0·1	—
Single Females	Non-Humid	75·4	24·6	18·9	4·6	1·1	—	—
	Humid	78·2	21·8	17 6	3·4	0·8	—	—
Married Females	Non-Humid	56·2	43·8	31·5	9·6	2 0	0 4	0 2
	Humid	55·6	44·4	30·1	10·9	2·5	0·6	0·2
Accrington—								
Males	Non-Humid	93 3	6·7	6·7	—	—	—	—
	Humid	83·3	16·7	14·3	2·4	—	—	—
Single Females	Non-Humid	81·8	18·2	15·9	2·3	—	—	—
	Humid	78·5	21·5	17·9	3·2	0·1	0·2	—
Married Females	Non-Humid	61·0	39·0	34·1	4·9	—	—	—
	Humid	61 0	39·0	29·5	8·0	1·5	—	—
Nelson—								
Males	Non-Humid	81·7	18·3	15·1	2·4	0·8	—	—
Single Females	Non-Humid	80 8	19·2	16·4	2·2	0·5	0·1	—
Married Females	Non-Humid	68·0	32·0	25·6	5·6	0·6	0·2	—
Blackburn—								
Males	Humid	83·5	16·5	13 0	2·5	1·0	—	—
Single Females	Humid	76·7	23·3	19·6	3·3	0 4	—	—
Married Females	Humid	60·8	39·2	30 3	7 7	1·0	0 2	—

* The Table reads: Of all the males exposed for the whole year in the non-humid sheds in Preston, 89·8 per cent. had no sickness during the year, 10·2 per cent had one or more periods of sickness, 9·0 per cent. were sick once, 0·8 per cent were sick twice, and 0·4 per cent were sick three times.

If these other factors be accepted as equal, then the humidity of the sheds of Blackburn cannot be said to cause, on the whole, more incapacity than the drier atmosphere of the Nelson mills.

If comparison is made between the sickness incidence in the other towns involved it will be of some value to know how they compare in certain of their vital indices. These are set out, together with those for Nelson and Blackburn, in Table XVII. All the towns are mainly occupied with the cotton industry.

TABLE XVII.—*Vital Statistics of Towns Investigated.*

Town	Population in 1921	Standardised Death-rate for 1925	No. of Persons per occupied house in 1921.	Remarks from Reports of Medical Officers of Health.
Preston ..	117,406	14·7	4·3	No evidence of gross over-crowding.
Burnley ..	103,157	15·6	3·9	General standard of houses good.
Accrington..	43,610	13·5	3·9	Very little serious over-crowding.
Nelson ..	40,690	13·0	4·1	Housing of very good type.
Blackburn ..	126,497	14·3	4·1	No real slum property but areas on the border line.

None of these indices seems to show any close connection with the amount of sickness found in the sample population of weavers. Burnley, with the highest death-rate, has some of the highest sickness rates, but, on the other hand, Nelson, with the lowest death-rate, has a sickness rate for males higher than that for Burnley and for single women on the same level. Preston and Accrington show quite similar sickness rates, though their death-rates differ slightly, and in housing its population Preston is at a disadvantage. The sickness rates found for the towns, however, do not fluctuate very widely, except for the males (if the married women's rate in Nelson be excluded) where the number of days' sickness per year of exposure varies, roughly, from five to nine. In the male group the number exposed to risk is least, so that possibly random fluctuations may account for these differences. At any rate the variations both in the rates of sickness and in the numbers falling sick are scarcely large enough to show correlation with the indices of Table XVII.

The State of Employment in the Non-Humid and the Humid Sheds and its relation to the Sickness Incidence.

One factor that may have some bearing upon the sickness incidence needs discussion at considerably more length. That is the question of unemployment. The year of investigation was one of trade depression for the cotton industry as a whole, a position which was made worse by the coal dispute and general strike of 1926. It is possible that such economic conditions may affect the amount of invalidity suffered by the community. For instance, it may lower the standard of living, perhaps to the detriment of health, so that sickness rates become unduly swollen. In addition to this possibility two lines of argument have been put forward. The first asserts that in times of unemployment or low wages the incentive to work is nil or small, and the incentive to draw sickness benefit is correspondingly greater. This argument does not necessarily contain any assumption of malingering, or of gaining sickness benefit without adequate reason. There are many forms of illness which will allow the worker to continue in employment in spite of their presence When the livelihood of a man and of his family depends upon his wages there is every incentive to remain at work in spite of sickness—for instance, influenza. If wages are low or nil this incentive disappears; the only form of income is the sickness benefit, which can justifiably be drawn. If this form of argument is correct, the times of unemployment will be times of abnormal sickness incidence. During the coal dispute it was pointed out by the Parliamentary Secretary to the Ministry of Health that the sickness claims met by the Approved Societies connected with the coal mining industry were very much above the normal level.*

The second line of argument runs counter to this. It points out that the rate of unemployment insurance pay is at a higher level than that for sickness, and suggests, therefore, that, in times of unemployment, sickness claims will be reduced by workers "signing on" as unemployed, instead of as sick. The abnormal sickness claims revealed during the coal dispute do not vitiate this argument, as persons involved in a trade dispute are debarred from drawing unemployment benefit, and, therefore, have not this alternative of a higher rate. It is not easy to prove or disprove either of these contentions; the possibilities they raise must be borne in mind, and the incapacity found in the humid and non-humid sheds examined in relation to them.

As an index of unemployment the number of days in the year, apart from normal holidays, that a mill was closed down has been utilized. Each employer made a return of all the periods *exceeding three days* in duration during which his mill was not working. This is admittedly only a rough guide for it takes no account of short time, or of certain weavers having to "play off," though the mill was running, or of each weaver working a smaller number of looms than normal. On the other hand it is a good

* *Hansard*. 202. H.C.Deb. 5 S. 21st February. Columns 1501–5

measure of the effects of the coal dispute when mills tended to close down entirely ; while, finally, it is the most drastic measure. When a mill is closed altogether, the wage becomes nothing ; on short time or on short production, there is some wage to be earned, most probably on a higher level than insurance benefit, and the incentive to "go sick" is not so strong. The suggestion is that if the index described does not show a correlation with the sickness incidence, then the minor forms of unemployment would not affect it either.

From the information given, the total number of days during the year that each mill was shut was calculated. This was multiplied by the number of weavers in the mill (male and female separately) giving the number of working days lost.* These lost working days were totalled for each town, and for all towns, and divided by the appropriate total number of weavers exposed giving thus the number of working days lost per weaver per town. The figures are set out in Table XVIII where it will be seen that considerable variations occur but that with the exception of Accrington the unemployment was greater in the non-humid sheds than in the humid sheds.†

TABLE XVIII.—*Number of Days of Unemployment‡ per weaver during the Year of Investigation, in each Town in the Non-Humid and Humid Sheds*

Town and Category.	Number of Days Unemployment per Weaver.	
	Males.	Females.
Preston—		
Non-Humid	40·4	17·1
Humid	21·7	13·4
Non-Humid (excluding one mill) ..	14·0	13·0
Humid (excluding one mill) ..	4·2	4·8
Burnley—		
Non-Humid	22·6	24·3
Humid	12·4	13·8
Accrington—		
Non-Humid	3·9	5·9
Humid	15·7	11·8
Nelson—Non-Humid	8·8	8·4
Blackburn—Humid	4·0	5·2
All Towns—		
Non-Humid	15·0	15·8
Humid	9·6	8·9
(Excluding the two Preston mills).		

* The number of weavers used was the number there at the time of the "census." To make allowance for the exits that had occurred before each date of closing down would be a task not justified by the consequent improvement made in the index.

† Three small mills (one dry and two wet) are excluded from this table owing to their having closed down altogether before the return was asked for. Their absence could make no material difference.

‡ Using as an index the number of days that each mill was closed down.

TABLE XIX.—*Sickness in Non-Humid Sheds in All Towns, excluding all Mills closed through Unemployment for more than* 11 *days in the year of inquiry.*

Age Group (age last birthday).	Person-years of exposure for Sickness.	Duration of Sickness in days.	Number of Claims.	Sickness Rate in days per person-year of exposure	Number of Claims per 100 person-years of exposure.
			Males		
15–24 ..	269·7	1,207	57	4·5	21·1
25–34 ..	254·6	1,800	80	7·1	31·4
35–44 ..	168·3	1,538	39	9·1	23·2
45–54 ..	190·5	2,091	45	11·0	23·6
55–64 ..	100·8	1,441	25	14·3	24·8
65–69 ..	18·3	716	7	39·0	38·2
All Ages ..	1,002·1	8,793	253	—	—
Crude Rate..	—	—	—	8·77	25·2
Standardised Rate	—	—	—	8·71	—
			Females (Single and Widowed).		
15–24 ..	871·4	5,699	201	6·5	23·1
25–34 ..	417·5	3,821	102	9·2	24·4
35–44 ..	219·1	3,301	66	15·1	30·1
45–54 ..	129·5	1,993	50	15·4	38·6
55–64 ..	61·1	1,281	27	21·0	44·2
65–69 ..	9·1	604	6	66·4	66·0
All Ages ..	1,707·7	16,699	452	—	—
Crude Rate..	—	—	—	9·78	26·5
Standardised Rate	—	—	—	9·52	—
			Females (Married).		
15–24 ..	102·4	2,625	65	25·6	63·5
25–34 ..	425·7	8,638	223	20·3	52·4
35–44 ..	330·4	5,694	150	17·2	45·4
45–54 ..	157·1	3,964	83	25·2	52·8
55–64 ..	30·3	817	14	27·0	46·2
65–69 ..	2·8	117	4	41·4	141·4
All Ages ..	1,048·8	21,855	539	—	—
Crude Rate..	—	—	—	20·84	51·4
Standardised Rate	—	—	—	20·89	—

In Preston the comparison does not give the true position as regards the total of mills, for two mills, one humid and one non-humid, were shut for a very protracted period. These two mills have been excluded and comparison is shown both with and without them.

The figures for all towns show that the dry sheds lost approximately one week more per weaver through unemployment than did the wet sheds. Turning back to the arguments previously outlined; if unemployment tends to swell unemployment claims

TABLE XX.—*Sickness in Humid Sheds in All Towns, excluding all Mills closed through Unemployment for more than* 11 *days in the year of inquiry.*

Age Group (age last birthday)	Person-years of exposure for Sickness.	Duration of Sickness in days.	Number of Claims.	Sickness Rate in days per person-year of exposure.	Number of Claims per 100 person-years of exposure.
		Males.			
15–24 ..	360·1	1,350	70	3·7	19·4
25–34 ..	350·1	2,083	89	5·9	25·4
35–44 .	233·8	997	42	4·3	18·0
45–54 ..	248 6	2,753	74	11·1	29·8
55–64	120·6	1 985	36	16·5	29·9
65–69 .	20·3	450	11	22·2	54·3
All Ages ..	1,333 4	9,618	322	—	—
Crude Rate..	—	—	—	7·21	24·1
Standardised Rate	—	—	—	7·33	—
		Females (Single and Widowed).			
15–24 ..	1,696·9	9,400	347	5·5	20·4
25–34 ..	732·3	5,722	175	7·8	23·9
35–44 ..	348 1	4,316	109	12·4	31·3
45–54 ..	217·8	2,743	70	12·6	32·1
55–64 ..	65·1	1,806	34	27·8	52·3
65–69 ..	12·7	413	7	32·4	55·0
All Ages ..	3,072·9	24,400	742	—	—
Crude Rate..	—	—	—	7·94	24·1
Standardised Rate	—	—	—	8·17	—
		Females (Married).			
15–24 ..	220·1	6,441	191	29·3	86·8
25–34 ..	999·9	19,277	558	19·3	55·8
35–44 ..	731·5	11,965	346	16·4	47·3
45–54 ..	327·3	6,464	136	19·8	41·6
55–64 ..	61·1	1,793	39	29·3	63·8
65–69 .	5·5	145	6	26·4	109·4
All Ages ..	2,345·3	46,085	1,276	—	—
Crude Rate..	—	—	—	19·65	54·4
Standardised Rate	—	—	—	19·81	—

and to reduce sickness claims, then the sickness found in the dry sheds is too low. It has already been seen that these sheds have a slightly higher incidence than the wet sheds; this form of argument would make them have a higher rate still, and therefore further nullify the contention that the humid environment is the more harmful.

On the other hand, if the first form of argument be true, that the unemployment swells the sickness claims, then the rates found in the non-humid sheds are higher than they should be in

relation to the rates in the humid sheds. This is a very important question. If the higher unemployment rate is the cause of the high level (relative to the wet sheds) of the sickness rate in the non-humid sheds, then the evidence given that there is no significant difference between the effects of the two environments is vitiated. To test the truth of the evidence already adduced the following method was applied.

From the sum total of the mills, selection was made of those having a small amount of unemployment in the year, those which were shut during the year of inquiry for more than two working weeks, i.e., eleven days, being rejected. This left a total of 11,159 weavers—somewhat over half the total population of the "census." The amount of time lost in the year in these mills was :—

Males	Non-humid	sheds	3·6 days
	Humid	sheds	4·8 days
Females	Non-humid	sheds	4·8 days
	Humid	sheds	3·5 days

The position, it will be seen, is just the reverse for the two sexes, but in either case the differences in the rates are too small to be taken as at all likely to be influential. The sickness and claim rates were then calculated for this population. They are set out in Tables XIX and XX. Taking the rates for all ages as a guide it will be seen that precisely the same result is reached for this group of mills as was previously reached for all the mills. The sickness rate is again slightly higher in the non-humid sheds for males and for both groups of females. The claim rate is slightly higher for the males and single females in the non-humid sheds, and a little lower for the married females. Again the differences are small but, on the other hand, such consistent results suggest that the dry sheds may actually suffer some disadvantage.

In Table XXI, for facility of comparison, are given the standardised rates found in all the mills and those found for this smaller group suffering from a low unemployment rate.

The close similarity between the rates found for the whole group and those for the smaller group is striking. The small difference that does exist makes the sickness rates slightly higher for the selected mills having low unemployment rates. Accordingly the remaining mills having higher unemployment rates must have lower sickness rates. In other words, the higher unemployment suffered in the dry sheds, as measured by the index obtained, is in no way responsible for the level of the sickness rates found in them.

If further evidence is required to prove that the rates in the dry sheds are not swollen artificially by unemployment it may be obtained by reference to some of the sickness rates found for the individual towns in relation to the amount of unemployment

TABLE XXI.—*Sickness rates and claim rates in All Mills compared with the rates in a Selection of Mills having a low amount of Unemployment in the year of investigation*

Group	Standardised Sickness Rate Days per person-year of exposure.		Crude Claim Rate. Claims per 100 person-years of exposure.	
	All Mills	Mills having low Unemployment Rate	All Mills	Mills having low Unemployment Rate.
Males—				
Non-Humid . .	8·18	8 71	23·7	25·2
Humid	7·24	7 33	24·4	24·1
Females (single and widowed)—				
Non-Humid .. .	9 38	9·52	27·4	26·5
Humid	7·92	8·17	25·1	24·1
Females (married)—				
Non-Humid . ..	20·77	20·89	52·5	51 4
Humid	19·96	19·81	54·3	54·4

experienced. In Preston the unemployment rate for the males in the non-humid sheds is two to three times the same rate in the humid sheds. Yet the sickness rate and number of claims were found (Tables VII and VIII) to be somewhat *lower* in the non-humid sheds where this high unemployment exists.

In Accrington the women in the humid sheds had twice as much unemployment, but their sickness rates and claim rates are lower than those in the non-humid sheds. In Nelson the unemployment rate is, approximately, only one-third of that found in the Burnley dry sheds, yet the sickness in the two groups is nearly on a par in the male and single female categories.

Thus, if the index of unemployment be accepted as adequate, it cannot be maintained that the trade depression in the year of inquiry has made unreliable the results reached. Indeed, the stability of the rates found when the mills are divided up into sections points to their accuracy and reduces very considerably the possibility of the result being due to the fluctuations of sampling.

The higher unemployment in the dry sheds is reflected slightly in the number of exits occurring. If the mills that were shut down altogether be excluded the number of exits from the non-humid sheds during the year was 11·8 per 100 operatives employed there on 1st August, 1925. From the humid sheds the corresponding number was 9·7, or 2 per 100 less.

It would be of some interest to see how many of the exits that took place from each type of mill were due to illness, but the data will not allow it. The definition of " due to illness " is too vague. An exit that took place at the beginning of or during an illness might be held to be caused by illness, but it is impossible to be certain that an exit that took place shortly *after* illness was or was not really due to illness. If all such exits were held to be caused by incapacity some arbitrary length of time must then be taken for " shortly after." The inaccuracies known to be present in the dates of exit given introduce another difficulty, while finally there was a tendency (which was corrected to the utmost extent) for some employers more than others to return as exits weavers who were absent ill and whose return to the mill was doubtful.

On the other hand the total number of exits, expressed as a rate, differs very little in the two types of mills, and the great majority of exits, it is known from the returns were definitely due to causes other than illness, i e. they related to weavers who suffered *no* incapacity during the year.* For these reasons it is very unlikely that any really crucial point is being overlooked by the lack of an analysis relating exits to periods of incapacity.

Classification of Mills according to their Temperature Readings, and relation of these Readings to the Sickness Incidence.

The contention that artificial humidification is a cause of excessive morbidity has not been borne out by a comparison of the humid with the non-humid sheds. The incidence does not differ, according to the results of this inquiry, under the two environments. The division of the two classes for comparison is a clear one, the criterion being the introduction of humidity by artificial means. By definition, all mills relying only on the natural moisture in the air are non-humid, all those resorting to some artificial means of increasing it are humid. Such a classification, on the other hand, makes no distinction between mills adding very different amounts of humidity or between mills so situated that they have very varied amounts of natural moisture present. Yet it is possible that the variations are not unimportant. A shed may stand upon a hillside exposed to drying winds and have a low natural moisture content; by increasing this content artificially it becomes "humid." Another shed may stand in a damp valley close to a piece of water, and have a high natural moisture content; it makes no addition to this content and is " non-humid." According to actual conditions, perhaps, the two mills should fall in the same class. In addition, certain trade processes, it is considered, demand a higher percentage of moisture in the atmosphere than do others, so that within the humid group itself there must exist an unknown amount of variation.

* In Burnley there were 508 exits, of whom only 66 left *at the beginning of or during an illness*; in Nelson, the proportion was 46 out of 455; in Blackburn, 65 out of 478; in Preston, 64 out of 646; in Accrington, 30 out of 927 (includes mills closing down).

The question then arises :—Is the division of the mills into the non-humid and humid categories an entirely sufficient one? It is the division, it is true, upon which the operatives base their statement of high sickness incidence, but such a division applied in this investigation does not bear out the statement. On the other hand, a classification of the mills based not upon the humid and non-humid criterion but upon the actual temperature and humidity conditions found in each mill during the period of inquiry, might reveal some differences in the sickness incidence which were obscured by the broader classification of wet and dry. Is a result found for the total humid and non-humid classes equally true for the extremes in those classes? and, is the sickness incidence found for each broad group the same for all parts of that group? To test this some further means of grouping the mills was sought.

The humid sheds are already required by statutory regulation to record daily readings of the wet and dry bulbs, and the amount of artificial humidity introduced is limited according to the position of these readings (see p. 4). No such regulations exist for the non-humid sheds, and no temperature records are kept. Therefore to obtain a comparative set of readings a hygrometer was placed in each dry shed and arrangements were made for two daily readings to be taken at the hours observed in the wet sheds (between 11 and 12 noon and 4 and 5 p.m.). Such readings were taken over five months, March to July, 1926. The records for both types of sheds were submitted to analysis, and a scheme of classification based upon these readings was adopted. It must be observed that not all the mills are included in this classification. Those that were shut for any prolonged length of time were excluded. This is obviously an essential step, for any scheme of classification must be based upon similar records. For instance if a mill were closed during July, a relatively hot month, the shed "characteristic" obtained for it from its four months' readings might differ considerably from that which would have been obtained from five months' readings. For this reason all mills were excluded that did not return 75 per cent. of the total possible readings during the five months. This eliminated 37 sheds and left a total of 91. It reduces the years of exposure at all ages for males from 4605·5 to 2932·0 ; for single females from 7993·9 to 5481·0 ; for married females from 5895·5 to 4042·3, by roughly one-third in each case. For each of these ninety-one sheds between 170 and 220 wet and dry bulb readings were supplied, and from each pair of readings can be calculated the relative humidity and physiological saturation deficit.* The problem is to reduce this large amount of material into a form concise enough to be used as a criterion for classification. Whatever measure be adopted no absolutely satisfactory result can be

* The wet and dry bulb readings are 'unventilated' readings; the relative humidity was calculated from Glaisher's Tables.

reached. The object is to relate to a year's invalidity a set of readings that vary from day to day and from hour to hour, and it is impossible to take this continual variation into account. Only the broad trend of the readings can be utilized. This trend is shown for the non-humid and humid types of shed in Table XXII and Fig. 1.

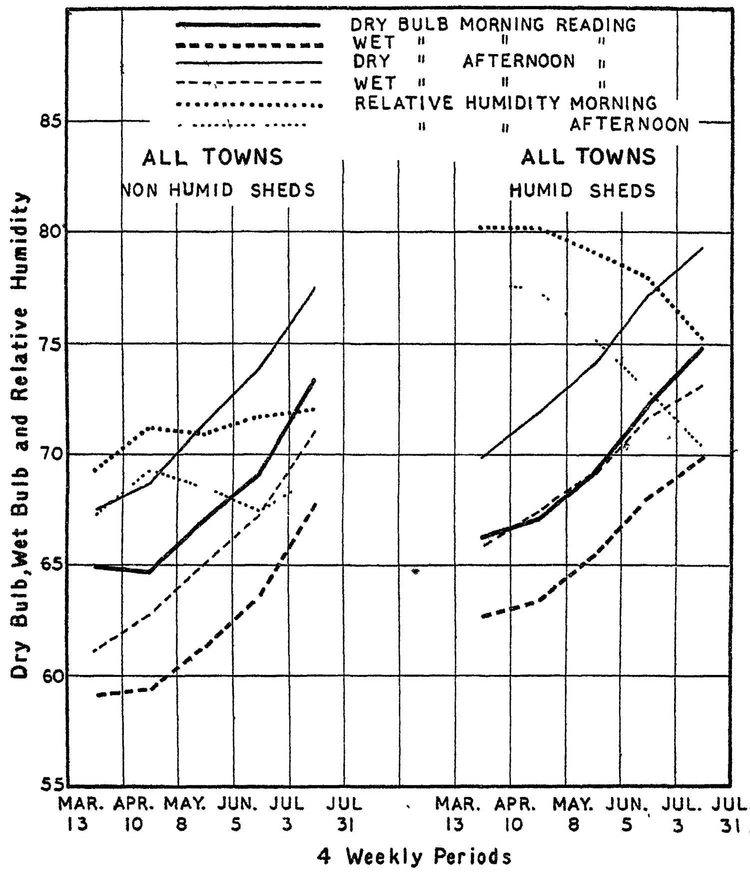

Fig. 1.

Comparing the two types it will be seen that the difference in dry bulb temperatures is not very great. The humid sheds as a whole are only, roughly, two to three degrees hotter than the non-humid. Their wet bulb temperatures on the other hand are, for nearly all the periods, between four and five degrees higher so that the two readings, the wet and the dry, are in closer juxtaposition in the humid sheds than in the non-humid.

The result of this is shown in the trend of the relative humidity which is distinctly different in the two types. In the dry sheds it tends to be constant or to rise slightly over the five months; in the wet sheds it starts at a far higher point and falls throughout

the period. The afternoon temperatures are higher than those found during the morning, but the relative humidity falls in both types of mills as the day goes on.

TABLE XXII.—*The Dry and Wet Bulb Readings and the Relative Humidity in the Mills investigated*

4-weekly Period.	Mean Reading for 4-weekly Period.					
	11 to 12 noon.			4 to 5 p.m.		
	Dry Bulb	Wet Bulb	Relative Humidity.	Dry Bulb	Wet Bulb	Relative Humidity.
	Non-Humid Mills.					
March 13 to April 10 ..	64·9	59·1	69·3	67·4	61·1	67·3
April 11 to May 8 ..	64·7	59·4	71·3	68·6	62 7	69·3
May 9 to June 5 ..	66·9	61·3	70·9	71 3	65·0	68·5
June 6 to July 3 ..	69·1	63·6	71·6	73·9	67·1	67·4
July 4 to July 31 ..	73·3	67·6	72·0	77·5	71·0	68·9
	Humid Mills.					
March 13 to April 10 ..	66·2	62·6	80·2	69·9	65·8	77·8
April 11 to May 8 ..	67·0	63·4	80·2	71·8	67·4	77·4
May 9 to June 5 ..	69·1	65·3	79·1	74·1	69·2	75·3
June 6 to July 3 ..	72·2	68·0	77·9	77·2	71·6	72·9
July 4 to July 31 ..	74·9	69·9	75·1	79·4	73·1	70·4

It is these differences that have so far been examined in relation to their effect upon the incidence of invalidity in the wet and dry sheds, and as a whole have been found to produce no significant variation in the amount of morbidity suffered. On the other hand in Table XXIII and Fig. 2, are shown the variations that may exist within these two categories, humid and non-humid. Comparison is made between two groups of mills in Nelson, and between two groups in Blackburn. In Nelson it will be seen that Group II has consistently higher temperatures than Group I, while the relative humidity falls over the five months in the one case, and rises in the other. In Blackburn in Group III, the relation of the wet to the dry bulb is nearly constant throughout the period, so that the level of the relative humidity shows very little variation. In Group IV the wet bulb reading falls further below that of the dry bulb as the temperature increases and consequently the relative humidity falls steeply. The differences shown thus to exist amongst the Nelson dry mills and the Blackburn wet mills, are clearly distinct. Such differences, more or less marked, are to be found amongst the mills in the other three towns while also in some cases, the curves for the wet and dry

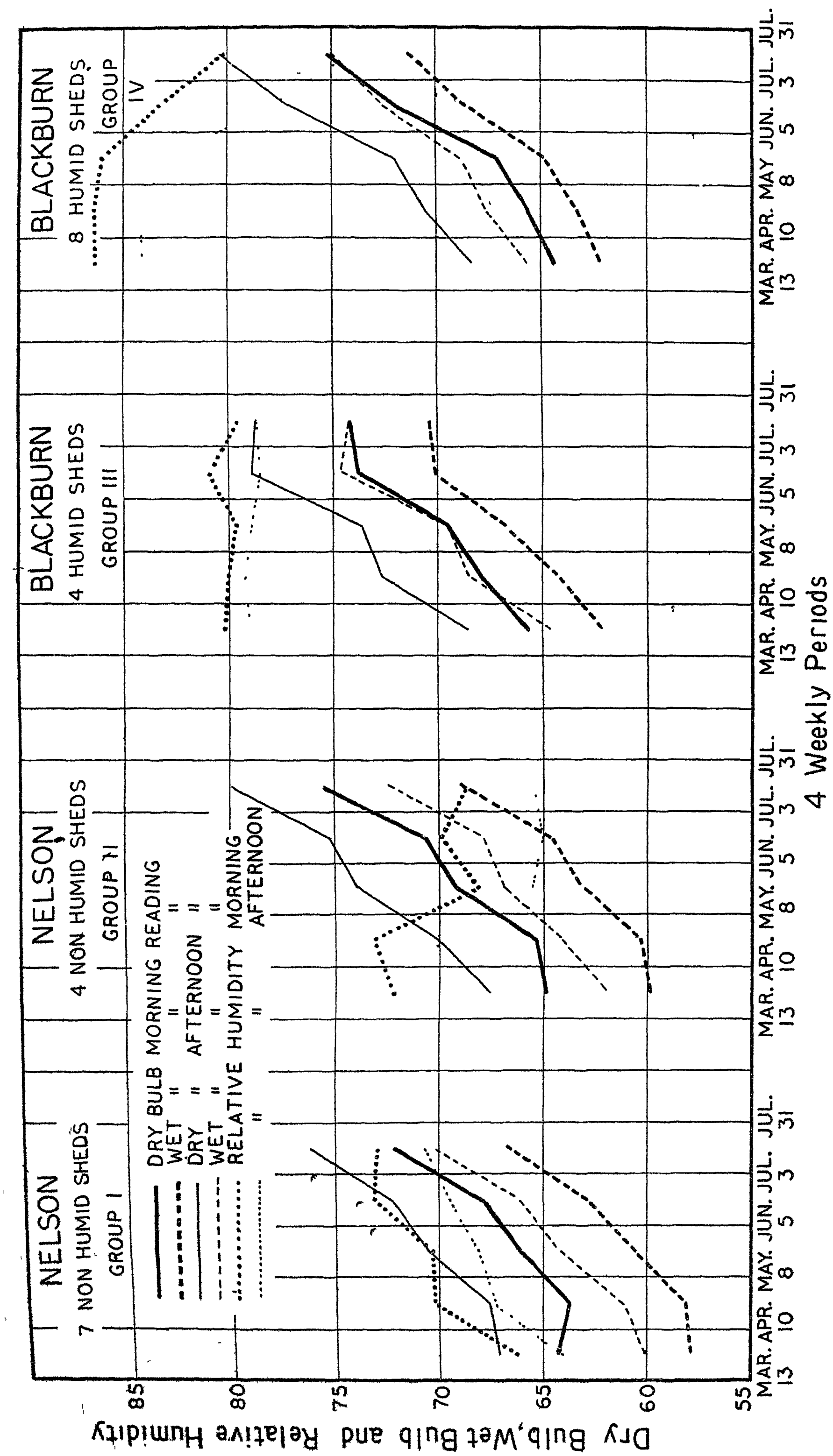
NELSON
7 NON HUMID SHEDS
GROUP I
NELSON
4 NON HUMID SHEDS
GROUP II
BLACKBURN
4 HUMID SHEDS
GROUP III
BLACKBURN
8 HUMID SHEDS
GROUP IV
DRY BULB MORNING READING
WET " " "
DRY " AFTERNOON "
WET " " "
RELATIVE HUMIDITY MORNING
" " AFTERNOON
Dry Bulb, Wet Bulb and Relative Humidity
85
80
75
70
65
60
55
MAR. APR. MAY. JUN. JUL. JUL. JUL.
13 10 8 5 3 31
4 Weekly Periods

Fig. 2.

sheds are not dissimilar. Such variation constitutes the argument in favour of deducing some shed characteristic based upon the temperature readings, and utilizing it as a method of classification.

TABLE XXIII.—*The Dry and Wet Bulb Readings and the Relative Humidity in Certain groups of Mills.*

4-weekly Period.	Mean Reading for 4-weekly Period.					
	11–12 noon			4–5 p m		
	Dry Bulb	Wet Bulb.	Relative Humidity	Dry Bulb	Wet Bulb.	Relative Humidity.
NELSON —*Group of* 7 *Non-Humid Sheds Group I*						
March 13 to April 10 .	64·3	57·9	66·1	67·0	60·0	64·2
April 11 to May 8 ..	63·7	58·1	70·1	67·5	61·2	67·3
May 9 to June 5.. .	66·0	60·5	70·2	70·4	64·1	68·1
June 6 to July 3 ..	67·8	62·8	73·1	72·2	66·0	69·5
July 4 to July 31 ..	72·1	66·7	72·9	76·1	70·2	70·6
NELSON.—*Group of* 4 *Non-Humid Sheds —Group II.*						
March 13 to April 10 ..	64·8	59·8	72·1	67·5	61·9	70·3
April 11 to May 8 .	65·3	60·3	73·1	70·0	64·1	70·0
May 9 to June 5 .. .	69·3	63·1	68·3	73·9	66·8	65·5
June 6 to July 3 .	70·6	64·7	69·8	75·2	67·8	65·0
July 4 to July 31 .	75·5	69·0	68·6	79·9	72·4	65·3
BLACKBURN —*Group of* 4 *Humid Sheds.—Group III*						
March 13 to April 10 ..	65·6	62·1	80·1	68·6	64·7	79·0
April 11 to May 8 .	67·9	64·3	80·0	72·6	68·6	79·3
May 9 to June 5.. ..	69·5	65·8	79·7	73·7	69·7	78·9
June 6 to July 3 ..	73·8	70·2	80·8	78·9	74·6	78·5
July 4 to July 31 ..	74·2	70·4	79·5	78·6	74·3	78·6
BLACKBURN —*Group of* 8 *Humid Sheds.—Group IV.*						
March 13 to April 10 ..	64·4	62·1	86·3	68·4	65·6	84·2
April 11 to May 8 ..	65·6	63·3	86·4	70·5	67·7	84·2
May 9 to June 5 . ..	67·2	64·8	86·0	72·0	68·8	82·9
June 6 to July 3 ..	71·8	68·6	83·3	77·0	72·5	77·9
July 4 to July 31 ..	75·2	71·4	80·1	80·4	75·0	73·9

Unfortunately, the numbers in such groups as are shown in Fig. 2, are too small to allow comparison to be made directly between them, while in addition some method of differentiating less distinct differences is required. The measure that has been used is the *mean*, calculated for each shed from all the readings, morning and afternoon, over the whole period. This is, admittedly, a very rough measure It takes very little account of the range or of the trend, or of the variation about the trend. In all mills, however, the movement of the wet and dry bulb temperatures is upwards over the five months, so that the trend in the

case of these readings is of small importance. In the relative humidity variations of trend are distinct (as is shown in Fig. 2) and a special grouping has, therefore, been carried out based upon the slope of the humidity curve, by which entire dependence upon grouping by the mean is obviated. This also makes allowance for the range of humidity. The variations about the trend are, in all cases, relatively unimportant. The movement is a fairly constant one, and no factor is likely to be overlooked by ignoring the fluctuations in 4-weekly periods. It would be an impossible task, as has been pointed out, to take into account the fluctuations from day to day and during each day.

In dividing the mills into groups the number exposed to risk in each group becomes small. It is important to bear this in mind in studying the tables that follow. The exposed to risk is given for each group, so that the size can be seen in every case. It will be obvious from the numbers that no faith can be placed in differences of sickness rates or claim rates unless the differences are consistent from group to group. Single differences, where small numbers are involved, are entirely unreliable. The rates given are the crude rates for all ages. The numbers exposed are far too small to allow division into age-groups, while standardisation, it has been found, makes no material difference to the rates. (This is based upon the standardisation of some sixty rates, of which only one differed from the crude rate by an amount approaching significance.)

Taking, first, the dry-bulb readings, the grouping and number of mills falling in each group were as follows :—

Mean Dry Bulb Reading.	*Number of Mills falling in Group.*	
° F.	*Non-Humid.*	*Humid.*
65·5 to 69·4	14	6
69·5 to 71·4	10	25
71·5 to 73·4	5	17
73·5 to 79·4	—	14

The sickness found in these groups is given in Table XXIV.

Examination of the sickness and claim rates reveals no increase in either as the temperature rises. This applies both to the non-humid and to the humid sheds. In the non-humid sheds the sickness rate shows a slight tendency to fall for both sexes as the dry bulb goes up, but the lack of a similar movement in the claim rate suggests that this is not significant. In the humid sheds the rates are remarkably stable for the males and single women; for the married women there is a greater fluctuation, but the exposed to risk in the first group is too small to allow any importance to be attached to the low sickness rate.

* The disablement recorded has been excluded in the following tables of comparison.

TABLE XXIV.—*Sickness in Mills grouped according to their Mean Dry Bulb Reading.**

Dry bulb Grouping °F.	NON-HUMID SHEDS.					HUMID SHEDS				
	Person-years of exposure to risk.	Total duration of Sickness in days.	Number of Claims	Sickness rate in days per person-year of exposure.	Claim rate in claims per 100 person-years of exposure.	Person-years of exposure to risk.	Total duration of Sickness in days.	Number of Claims	Sickness rate in days per person-year of exposure.	Claim rate in claims per 100 person-years of exposure.
				All Ages, Crude Rates					All Ages, Crude Rates.	
Males—										
65·5–69·4 ..	492·1	4,581	99	9·3	20·1	135·8	1,032	35	7·6	25·8
69·5–71·4 ..	531·3	5,301	136	10·0	25·6	643·3	4,793	148	7·5	23·0
71·5–73·4 ..	379·2	2,381	88	6·3	23·2	383·6	2,361	88	6·2	22·9
73·5–79·4 ..	—	—	—	—	—	366·8	2,664	92	7·3	25·1
Females (Single and Widowed)—										
65·5–69·4 ..	703·4	7,723	185	11·0	26·3	325·5	2,555	81	7·8	24·9
69·5–71·4 ..	701·2	6,326	171	9·0	24·4	1,134·1	9,832	313	8·7	27·6
71·5–73·4 ..	537·2	4,376	135	8·1	25·1	1,148·7	8,747	279	7·6	24·3
73·5–79·4 ..	—	—	—	—	—	930·8	7,566	227	8·1	24·4
Females (Married)—										
65·5–69·4 ..	388·1	8,410	180	21·7	46·4	238·3	3,562	104	14·9	43·6
69·5–71·4 ..	547·5	9,449	240	17·3	43·8	940·5	21,404	556	22·8	59·1
71·5–73·4 ..	323·6	5,803	172	17·9	53·2	909·0	17,870	524	19·7	57·6
73·5–79·4 ..	—	—	—	—	—	695·4	12,740	342	18·3	49·2

* The mean in this and the following Tables is the mean of all the readings, morning and evening, over the five months March to July, 1926.

In Table XXV are given the rates resulting from grouping these mills according to their wet bulb readings. The grouping was as follows :—

Mean Wet Bulb Reading. °F.	*Number of Mills falling in Group.* *Non-Humid.*	*Humid.*
59–64	22	7
65–68	7	42
69–74	—	13

The sickness rates in each of these groups do not suggest that the rise in the wet bulb affects the incidence. In the non-humid sheds there is, considering the size of the second group, very little difference between both the sickness rates and claim rates. In the humid sheds this time there is a tendency for the sickness and claims to fall as the wet bulb rises, but the smallness of the first group throws doubt upon its significance, while the last two groups have very similar rates both for sickness and claims for each sex. If the rates for the dry and wet sheds within each group be compared there is no evidence that the humid sheds have the higher incidence. In most cases the differences are slight, while if the extremes be compared, the 59–64° dry group with the 69–74° wet group, the dry group is at a disadvantage.

Using the relative humidity* as a criterion the grouping was as follows :—

Relative Humidity (*Non-Humid.*)	*No. of Mills falling in Group.*	*Relative Humidity.* (*Humid.*)	*No. of Mills falling in Group.*
57–63	4	64–68	5
64–70	10	69–73	11
71–77	15	74–78	21
—	—	79–86	25

The sickness figures for these groups are set out in Table XXVI. In the non-humid sheds there is some rise in the sickness rates for the men and single women as the relative humidity increases ; for the married women the rate rises and falls again. The claim rate in all three groups rises and then falls again. Only in the case of the married women does there appear to be any significant difference between the rates found in the two larger groups, 64–70 and 71–77, and there the rate falls as the humidity rises.

In the humid sheds the rates for the males, based upon relatively small numbers, show some fluctuation, but no consistent movement either for sickness or claims. For the single women the rate is low in the first and small group ; after that the incidence of sickness remains quite steady in spite of the rising humidity. The married women have similarly stable rates in the first three groups, while in the final group when the humidity is at its highest the time lost by sickness is at its lowest. The number of claims, on the other hand, cannot be said to show any significant variation throughout.

* The relative humidity is the amount of moisture in the air at any given temperature expressed as a percentage of the amount of moisture that would be needed to saturate the air at that temperature. It was calculated from Glaisher's Tables for each recorded wet and dry bulb reading.

TABLE XXV.—*Sickness in Mills grouped according to their Mean Wet Bulb Reading.*

Wet bulb Grouping. °F.	NON-HUMID SHEDS					HUMID SHEDS				
	Person-years of exposure to risk.	Total duration of Sickness in days.	Number of Claims	Sickness rate in days per person-year of exposure	Claim rate in claims per 100 person-years of exposure.	Person-years of exposure to risk.	Total duration of Sickness in days	Number of Claims	Sickness rate in days per person-year of exposure	Claim rate in claims per 100 person-years of exposure.
				All Ages, Crude Rates.					All Ages, Crude Rates.	
Males—										
59–64 ..	1,086·7	9,127	247	8·4	22·7	264·7	2,440	75	9·2	28·3
65–68 ..	316·0	3,136	76	9·9	24·1	976·9	6,656	216	6·8	22·1
69–74 ..	—	—	—	—	—	287·9	1,754	72	6·1	25·0
Females (Single and Widowed)—										
59–64 ..	1,339·7	13,201	345	9·9	25·8	363·3	3,909	114	10·8	31·4
65–68 ..	602·2	5,224	146	8·7	24·2	2,288·1	18,013	572	7·9	25·0
69–74 ..	—	—	—	—	—	887·7	6,778	214	7·6	24·1
Females (married)—										
59–64 ..	863·9	16,725	400	19·4	46·3	342·0	8,604	208	25·2	60·8
65–68 ..	395·2	6,937	192	17·6	48·6	1,818·2	35,496	997	19·5	54·8
69–74 ..	—	—	—	—	—	623·0	11,486	321	18·4	51·5

TABLE XXVI.—*Sickness in Mills grouped according to their Mean Relative Humidity.*

Relative Humidity Grouping.	NON-HUMID SHEDS. Person-years of exposure to risk.	Total duration of Sickness in days.	Number of Claims	Sickness rate in days per person-year of exposure. (All Ages, Crude Rates.)	Claim rate in claims per 100 person-years of exposure. (All Ages, Crude Rates.)	Relative Humidity Grouping.	HUMID SHEDS. Person-years of exposure to risk.	Total duration of Sickness in days	Number of Claims	Sickness rate in days per person-year of exposure. (All Ages, Crude Rates.)	Claim rate in claims per 100 person-years of exposure. (All Ages, Crude Rates.)
Males—											
57–63 ..	158·3	1,008	27	6·4	17·1	64–68 ..	234·5	2,138	57	9·1	24·3
64–70 ..	684·9	5,824	167	8·5	24·4	69–73 ..	456·7	3,447	119	7·5	26·1
71–77 ..	559·7	5,431	129	9·7	23·0	74–78 ..	369·6	2,108	77	5·7	20·8
						79–86 .	468·7	3,157	110	6·7	23·5
Females (Single and Widowed)—											
57–63 ..	256·0	1,764	47	6·9	18·4	64–68 ..	398·8	2,801	73	7·0	18·3
64–70 ..	767·6	7,350	219	9·6	28·5	69–73 ..	712·1	6,198	202	8·7	28·4
71–77 ..	918·0	9,311	225	10·1	24·5	74–78 ..	1,163·5	9,556	298	8·2	25·6
						79–86 ..	1,264·8	10,145	327	8·0	25·9
Females (Married)—											
57–63 ..	161·6	2,341	67	14·5	41·5	64–68 ..	254·2	5,165	132	20·3	51·9
64–70 ..	532·1	11,783	278	22·1	52·2	69–73 ..	620·8	13,252	343	21·3	55·3
71–77 ..	565·2	9,538	247	16·9	43·7	74–78 ..	854·3	17,771	493	20·8	57·7
						79–86 ..	1,054·4	19,388	558	18·4	52·9

The conclusion from these tables is that there is no increase shown in the amount of sickness suffered, as the dry and wet-bulb temperatures move upward and the relative humidity grows higher.

On the other hand, comparison based upon the *absolute* rates is not entirely sufficient. The relative humidity is a measure of the relation of the wet bulb to the dry bulb that takes no account of the actual level of the wet or dry bulb. For instance, with a dry bulb of 65° F. and a wet bulb of 62°F. the relative humidity stands at 83. When, however, the dry bulb has moved up to 71° F. and the wet bulb to 68°F. the relative humidity still stands at the same figure, 83. It is possible that the humidity at a higher temperature has a very different physiological effect from that produced by the same humidity at a lower temperature. Therefore, the question to be answered is: Do the *humidities* found in the mills *in relation to the temperatures* there existent affect the sickness incidence to any appreciable extent? A grouping has been made on this basis, and is as follows.—*

Mean Relative Humidity and Wet Bulb — *Wet Bulb °F.*	*Relative Humidity.*	*No of Mills falling in Group Non-Humid.*	*No of Mills falling in Group Humid.*
59–63	59–72	11	—
64–68	59–72	8	10
64–68	73–79	6	25
64–68	80–86	—	14
69–73	73–86	—	5

The sickness incidence in these groups is given in Table XXVII. Again nothing but seemingly random fluctuations is apparent in the rates. In both types of mills in some groups there is a very slight suggestion of *falling* sickness rates as the temperature and humidity grows *higher*, but the movement of the claim rate does not confirm this, while for the males in the dry sheds and for the single women in both types the rates are virtually stationary. Taking as a criterion the two rates together, i.e., that for sickness and that for claims, there is no significant difference at all apparent in the incidence of sickness over the range of temperatures and humidities found to exist in this sample of mills.

A further grouping has been carried out using the wet bulb readings in conjunction with the physiological saturation deficit.† The physiological saturation deficit is the difference between the water vapour in the air at the atmospheric temperature and that which can be held in the air when saturated at body temperature. It is held to be of importance both to health and comfort. "A large physiological saturation deficit keeps the clothes dry, and the body feels warm because the conductivity of the entangled

* A few mills of both types fall outside these groups and are too small in number to form groups of their own. They have, therefore, been excluded.

† The absolute level of the physiological saturation deficit taken alone showed no significant differences in sickness experience.

TABLE XXVII.—*Sickness in Mills grouped according to their Mean Wet Bulb in conjunction with their Mean Relative Humidity.*

Wet bulb °F.	Rel. Hum.	Non-Humid Sheds: Person-years of exposure to risk.	Non-Humid Sheds: Total duration of Sickness in days.	Non-Humid Sheds: Number of Claims	Non-Humid Sheds: Sickness rate in days per person-year of exposure.	Non-Humid Sheds: Claim rate in claims per 100 person-years of exposure.	Humid Sheds: Person-years of exposure to risk	Humid Sheds: Total duration of Sickness in days	Humid Sheds: Number of Claims	Humid Sheds: Sickness rate in days per person-year of exposure	Humid Sheds: Claim rate in claims per 100 person-years of exposure.
					All Ages, Crude Rates.					All Ages, Crude Rates.	
Males—											
59–63	59–72	462·9	3,799	83	8·2	17·9	—	—	—	—	—
64–68	59–72	674·0	6,057	183	9·0	27·1	501·7	4,398	130	8·8	25·9
64–68	73–79	150 4	1,283	32	8·5	21·3	528·2	3,323	110	6·3	20·8
64–68	80–86	—	—	—	—	—	211·7	1,375	51	6·5	24·1
69–73	73–86	—	—	—	—	—	287 9	1,754	72	6·1	25·0
Females	(Single and Widowed)—										
59–63	59–72	697·8	7,157	172	10·3	24·7	—	—	—	—	—
64–68	59–72	624·5	5,557	177	8·9	28·3	751·1	6,195	187	8·2	24·9
64–68	73–79	425·3	3,915	97	9·2	22·8	1,292·2	11,091	337	8 6	26·1
64–68	80–86	—	—	—	—	—	608·2	4,636	162	7·6	26·6
69–73	73–86	—	—	—	—	—	887·7	6,778	214	7 6	24·1
Females	(Married)—										
59–63	59–72	400·7	8,100	182	20·2	45·4	—	—	—	—	—
64–68	59–72	477·8	9,338	245	19·5	51·3	608·0	14,134	364	23·2	59·9
64–68	73–79	282·5	4,611	122	16·3	43·2	1,070·6	21,592	592	20·2	55·3
64–68	80–86	—	—	—	—	—	481·6	8,364	249	17·4	51·7
69–73	73–86	—	—	—	—	—	623·0	11,486	321	18·4	51·5

dry air is much less. It keeps the skin relatively dry and comfortable from this dryness, and greatly enhances the evaporation from, and flow of blood and lymph through, the respiratory membrane."*

The higher the percentage of moisture already in the air the less moisture can the air breathed in evaporate from the lungs and respiratory membrane, so that the less does this cleansing mechanism work. " In a spinning mill or weaving shed, when the dew-point is 70°F. (21°C), the vapour pressure is 18½ mm. and the physiological saturation deficit for the lungs is 37–18½= 18½ mm. in place of 30 to 32 out of doors (winter months), supposing the expired air to be saturated and at 33°C. In other words, every cubic metre of air breathed takes up 12 to 13 less gm. of water than out of doors Between the spinning mill and the Alpine health resort this difference is 14 to 15 gm If 10 cu.m. of air are breathed in the day, this means 140–150 gm. more water are evaporated each day from the lungs of a man breathing the open air in the Alps than in the case of the cotton spinner."†

On the other hand, the differences found to exist in the mills investigated, set out below, do not seem to be sufficiently large to be reflected significantly in the sickness rates (given in Table XXVIII).

Wet Bulb and Physiological Saturation Deficit Grouping		No of Mills in Group	Wet Bulb and Physiological Saturation Deficit Grouping.		No of Mills in Group.
Wet Bulb °F.	P S D Inches ‡	Non-Humid §	Wet Bulb. °F	P S D. Inches	Humid
60–64	0 925 to 0·974	11	64–68	0·751 to 0·850	11
60–64	0·975 to 1·025	9	64–68	0·851 to 0 900	22
65–69	0 851 to 0·950	7	64–68	0·901 to 1·050	16
—	—	—	69–75	0·751 to 0·850	13

In the non-humid sheds there is a slight but not significant fall in the sickness rate as the deficit becomes higher, the wet bulb remaining constant. As the wet bulb temperature moves up and the deficit falls, i.e., as conditions become more unfavourable, there is a suggestion of a significant rise in the rate (more

* Sunshine and Open Air. p 27 Leonard Hill, M.B., F R S , Edward Arnold and Co. London. 1925.

† Ibid. pp. 27–28.

‡ Each reading is the vapour pressure at the recorded atmospheric dry and wet bulb temperatures subtracted from 1·464 in., the vapour pressure of saturated air at 91·2° F , the body temperature at which air is expired.

§ Two sheds fall without these groups and are excluded.

TABLE XXVIII.—*Sickness in Mills grouped according to their Mean Wet Bulb in conjunction with their Mean Physiological Saturation Deficit.*

NON-HUMID SHEDS.							HUMID SHEDS.						
Wet Bulb and Physiological Saturation Deficit Grouping.		Person-years of exposure to risk.	Total duration of Sickness in days.	No. of Claims.	Sickness rate in days per person-year of exposure.	Claim rate in claims per 100 person-years of exposure.	Wet Bulb and Physiological Saturation Deficit Grouping.		Person-years of exposure to risk	Total duration of Sickness in days.	No. of Claims.	Sickness rate in days per person-year of exposure.	Claim rate in claims per 100 person-years of exposure.
Wet bulb. °F.	P.S.D. inches.						Wet bulb °F	P.S.D. inches.					
					All Ages, Crude Rates.							All Ages, Crude Rates.	
Males—													
60–64	0·925 to 0·974	660·0	5,787	176	8·8	26·7	64–68	0·751 to 0·850	108·3	639	19	5·9	17·5
60–64	0·975 to 1·025	411·7	3,330	70	8·1	17·0	64–68	0·851 to 0·900	445·4	2,399	93	5·4	20·9
65–69	0·851 to 0·950	316·0	3,136	76	9·9	24·1	64–68	0·901 to 1·050	688·0	6,058	179	8·8	26·0
							69–73	0·751 to 0·850	287·8	1,754	72	6·1	25·0
Females (Single and Widowed)—													
60–64	0·925 to 0·974	633·4	5,732	168	9·0	26·5	64–68	0·751 to 0·850	506·7	3,780	133	7·5	26·2
60–64	0·975 to 1·025	602·3	5,224	146	8·7	24·2	64–68	0·851 to 0·900	1199·0	9,674	303	8·1	25·3
65–69	0·851 to 0·950	657·6	7,235	168	11·0	25·5	64–68	0·901 to 1·050	945·8	8,468	250	9·0	26·4
							69–73	0·751 to 0·850	887·7	6,778	214	7·6	24·1
Females (Married)—													
60–64	0·925 to 0·974	452·5	8,717	216	19·3	47·7	64–68	0·751 to 0·850	472·8	9,286	279	19·6	59·0
60–64	0·975 to 1·025	395·0	6,937	192	17·6	48·6	64–68	0·851 to 0·900	949·2	17,782	488	18·7	51·4
65–69	0·851 to 0·950	366·4	7,285	164	19·9	44·8	64–68	0·901 to 1·050	738·7	17,022	438	23·0	59·3
							69–73	0·751 to 0·850	623·0	11,486	321	18·4	51·5

pronounced for men and single women). On the other hand the claim rate gives no supporting evidence and there is no similar movement within the humid sheds. Amongst these the sheds with higher wet bulb temperatures and lower deficits show to no disadvantage when compared either with wet sheds with more favourable readings or even with the substantially better non-humid sheds. In view of this it is difficult to attach significance to the movement (based upon small figures) in the dry sheds.

The final grouping that has been carried out relates to the relative humidity of which, it has been pointed out, the mean is not a very satisfactory measure owing to the variation in trend. Two groups of humid sheds have been chosen based upon the charts of the movement of their relative humidity over the five months' readings. The first group comprises mills with an initial very high relative humidity falling off rapidly as the summer temperatures increase (as in Group IV, Fig. 2). The second group comprises mills with considerably lower humidities, stationary or slowly falling during the five months. The sickness is set out in Table XXIX. There is very little difference between the two groups in the number of claims made but the *low* humidity group have a higher sickness rate (amounting to roughly a day and a half in each case) which must be caused, since the claim rates are equal, by sickness of longer duration. Actually these differences are caused by the presence in the second group of a few more cases of long sicknesses extending into disablement. For instance for the males there were some six such cases in the low humidity group and only one in the high group ; for single women there were some nine such cases in the former, three in the latter group. With relatively small groups this is sufficient to account for the discrepancy in sickness rates, and eliminating them makes the rates in each group very similar. The difference in sickness incidence is thus due only to the presence of a few persons which affects unduly one group owing to the smallness of numbers therein, and such difference cannot therefore be held to possess any significant meaning for the groups as a whole.*

The final conclusion from this variety of groupings based upon the temperature records obtained from the mills is that no significant connection can be traced between the sickness incidence experienced and the range of temperatures and humidities existent in either type of weaving shed. Sickness shows no greater prevalence in the hotter or more humid mills, within the range of variation here examined.†

* It is of interest to note thus the fluctuations that may occur in the rates found in small groups due to a very small proportion of the exposed to risk.

† Such a conclusion, obviously, could not be applied to atmospheric conditions materially outside this range.

TABLE XXIX.—*Sickness in two Groups of Humid Mills, grouped according to the character and trend of their Relative Humidity over five months.*

	Person-years of exposure to risk.	Total duration of Sickness in days	Number of Claims.	Sickness rate in days per person-year of exposure	Claim rate in claims per 100 person-years of exposure
Humid Mills.				All Ages, Crude Rates.	
With high and rapidly falling relative humidity.					
Males	398·3	2,549	95	6·4	23·9
Females (single and widowed)	1,120·4	8,284	283	7·4	25·3
Females (married)	914·9	18,030	525	19·7	57·4
With low and slowly falling or stationary relative humidity.					
Males	603·1	4,760	158	7·9	26·2
Females (single and widowed)	1,127·3	10,015	291	8·9	25·8
Females (married)	861·0	18,039	498	21·0	57·8

So far the comparison has been based upon all forms of sickness. It remains to examine into the *cause* of sickness and to see whether any types are prevalent to a greater extent in the humid as compared with the non-humid sheds.

Analysis of Sickness by Cause.

For the purpose of comparing the nature of the morbidity suffered in the humid and non-humid sheds, thirteen main cause groups have been adopted. These groups are as follow :—

1. *Influenza.*—Influenza, post-influenzal debility, influenzal cold, etc.
2. *Phthisis.*—Phthisis, haemoptysis, tuberculosis, etc.
3. *Rheumatism*—Rheumatism, sciatica, lumbago, perichondritis, myositis, synovitis, bursitis, arthritis, fibrositis, myalgia, torticollis, etc.
4. *Diseases of the Respiratory System.*—Bronchitis, pneumonia, polypus, asthma, pleurisy, cold, pleurodynia, coryza, catarrh, emphysema, rhinitis, etc
5. *Diseases of the Circulatory System*—Anaemia, chlorosis, angina pectoris, arterial sclerosis, aneurysm, dropsy, mitral disease, phlebitis, varicose veins, tachycardia, purpura, morbis cordis, piles, haemorrhoids, ulcerated leg, endocarditis, pericarditis, myxoedema, etc.
6. *Diseases of the Digestive System*—Sore throat, tonsilitis, laryngitis, ulcerated throat, constipation, diarrhoea, dysentery, hernia, dyspepsia, indigestion, gastritis, gastric catarrh, gastric ulcer, colitis, gallstones, colic, peritonitis, etc.
7. *Diseases of the Nervous System.*—Thrombosis, embolism, insanity, neurasthenia, hysteria, neuritis, epilepsy, neuralgia, nervous debility, vertigo, myelitis, insomnia, chorea, faints, etc.
8. *Diseases of the Skin.*—Erythema, erysipelas, dermatitis, impetigo, urticaria, herpes zoster, abscess, adenitis, cellulitis, pyaemia, glands, boils, furunculosis, septic sores, etc
9. *Diseases of the Urinary System.*—Nephritis, Bright's disease, renal stricture, cystitis, calculus, etc.
10. *Diseases of the Reproductive System.*—Orchitis, menorrhagia, epididymitis, dysmenorrhoea, salpingitis, endometritis, mastitis, climacteria, etc.
11. *Other Causes.*—Cancer, gout, podagra, diabetes, debility, asthenia, otitis media, mastoid disease, conjunctivitis, glaucoma, myopia, ophthalmia, chicken pox, measles, scarlet fever, mumps, parotitis, diphtheria, quinsy, pyrexia, chill, malaria, febricula, migraine, rheumatic fever, acute rheumatism, cyst, carbuncle, fistula, osteitis, necrosis, jaundice, dental trouble, etc
12. *Accidents.*—Accidents, burns, sprains, etc.*
13. *Pregnancy.*—Confinement, illnesses arising from pregnancy.

In a very few cases the cause of illness was not stated, and these cases have been excluded. Disablement, as in the previous tables just discussed, was not included in the calculations. Where two causes were given or a change in diagnosis was made during the period of incapacity the sickness has been grouped under the major cause (as far as possible guidance was obtained

* As previously pointed out, cases of Workmen's Compensation were excluded from the experience.

from the Manual of the International List of Causes of Death as used for the classification of deaths in England and Wales) or under the cause which was responsible for the main part of the time lost through the sickness. No difficulty was experienced in grouping accurately the great majority of the sicknesses, but in a small percentage some arbitrary rule had to be followed. For example such a diagnosis may have appeared as "influenza and rheumatism" and it is not possible to assign the sickness to Group I rather than to Group III or vice versa. In such cases (they were small in number) the same procedure was followed for both types of sheds so that in comparison of the two no fallacy can exist. The amount of sickness due to each cause that occurred in all the humid and the non-humid sheds is set out in Table XXX. The actual duration of sickness suffered and the number of claims made are given so that in comparing the rates the figures upon which they are based can be taken into account. Taking the rates of sickness cause by cause:—

Influenza.—For males the sickness rate and claim rate are slightly higher in the humid sheds. For the single women the reverse is seen, those in the non-humid sheds being at a disadvantage. For the married women the number of days of sickness is the same in both environments, the number of claims slightly higher in the wet sheds. Thus, as a whole, influenza shows no significant difference in incidence in the two groups of sheds.

Phthisis.—The number of claims arising from this cause are too few to make comparison of any importance. No difference is to be found in the claim rate throughout.

Rheumatism.—For the males the rates are very similar in both environments. Both the single and married women have more claims and more days of sickness in the dry sheds but the differences, especially for the married women, are small. Taken as a whole no significant difference in incidence is revealed.

Respiratory Diseases.—The males suffer from adverse rates in the humid sheds and the difference is large enough to suggest significance. The single women in the wet sheds are similarly at a disadvantage, but the differences in the rates are very much smaller. For the married women the position is reversed, those under non-humid conditions suffering from the higher rates, the difference not being large enough to command confidence. Taken as a whole there is a suggestion that the males suffer more from respiratory diseases under the humid conditions but this higher incidence is not confirmed by the rates suffered by women.

Diseases of the Circulatory System.—For males the claim rate is the same in both types of shed, the duration of sickness is longer in the non-humid sheds. For single women, claims and number of days of sickness suffered are both higher in the non-humid sheds. For married women the differences are negligible. Taken as a whole this cause shows no significant difference in incidence in the two environments.

TABLE XXX.—*Sickness (disablement not included) grouped according to Cause of Incapacity.*

ALL TOWNS.—HUMID AND NON-HUMID SHEDS

Cause Group	Non-Humid Sheds: Total duration of Sickness in days	Non-Humid Sheds: Number of Claims made	Non-Humid Sheds: Number of days sickness per person-year of exposure.	Non-Humid Sheds: Number of Claims per 100 person-years of exposure	Humid Sheds: Total duration of Sickness in days.	Humid Sheds: Number of Claims made	Humid Sheds: Number of days sickness per person-year of exposure.	Humid Sheds: Number of claims per 100 person-years of exposure.
(1)	(2)	(3)	(4)*	(5)*	(6)	(7)	(8)	(9)
				Males.				
I.—Influenza	2,568	104	0·97	3·9	2,291	91	1·18	4·7
II.—Phthisis	421	4	0·16	0·2	47	2	0·02	0·1
III.—Rheumatism	2,276	70	0·86	2·6	1,590	45	0·82	2·3
IV.—Respiratory	2,590	78	0·97	2·9	2,502	75	1·29	3·9
V.—Circulatory	2,306	37	0·87	1·4	968	30	0·50	1·5
VI.—Digestive	4,940	130	1·86	4·9	2,670	93	1·37	4·8
VII.—Nervous	1,339	34	0·50	1·3	665	18	0·34	0·9
VIII.—Skin	1,403	52	0·53	2·0	1,218	41	0·63	2·1
IX.—Urinary	400	9	0·15	0·3	145	4	0·08	0·2
X.—Reproductive	—	—	—	—	106	4	0·06	0·2
XI.—Other Causes	1,962	60	0·74	2·3	1,270	40	0·65	2·1
XII.—Accidents	1,510	50	0·57	1·9	630	31	0·32	1·6
XIII.—Pregnancy	—	—	—	—	—	—	—	—
Number of person-years of exposure	2661·0				1944·5			
				Females (Single and Widowed).				
I.—Influenza	4,958	174	1·42	5·0	5,208	212	1·16	4·7
II.—Phthisis	813	8	0·23	0·2	728	9	0·16	0·2
III.—Rheumatism	3,432	87	0·98	2·5	2,826	83	0·63	1·9
IV.—Respiratory	3,159	91	0·90	2·6	4,528	126	1·01	2·8
V.—Circulatory	4,601	94	1·32	2·7	4,184	100	0·93	2·2
VI.—Digestive	6,914	221	1·98	6·3	6,883	240	1·53	5·3
VII.—Nervous	2,669	62	0·76	1·8	1,989	67	0·44	1·5
VIII.—Skin	1,378	67	0·39	1·9	2,601	100	0·58	2·2
IX.—Urinary	478	11	0·14	0·3	320	10	0·07	0·2
X.—Reproductive	1,215	26	0·35	0·7	1,017	30	0·23	0·7
XI.—Other Causes	2,325	75	0·67	2·1	3,383	88	0·75	2·0
XII.—Accidents	964	37	0·28	1·1	1,351	48	0·30	1·1
XIII.—Pregnancy	105	5	0·03	0·1	206	6	0·05	0·1
Number of person-years of exposure.	3497·2				4496·7			
				Females (Married).				
I.—Influenza	5,325	182	2·15	7·3	7,273	274	2·13	8·0
II.—Phthisis	205	4	0·08	0·2	323	5	0·10	0·2
III.—Rheumatism	5,449	141	2·20	5·7	6,813	174	2·00	5·1
IV.—Respiratory	5,321	147	2·15	5·9	6,998	195	2·05	5·7
V.—Circulatory	6,374	137	2·57	5·5	8,062	198	2·36	5·8
VI.—Digestive	8,921	247	3·60	10·0	10,119	302	2·96	8·8
VII.—Nervous	2,915	85	1·18	3·4	4,237	114	1·24	3·3
VIII.—Skin	2,314	60	0·93	2·4	2,080	67	0·61	2·0
IX.—Urinary	617	19	0·25	0·8	1,775	34	0·52	1·0
X.—Reproductive	4,591	86	1·85	3·5	4,372	99	1·28	2·9
XI.—Other Causes	2,595	57	1·05	2·3	3,916	113	1·15	3·3
XII.—Accidents	1,132	36	0·46	1·5	1,701	52	0·50	1·5
XIII.—Pregnancy	5,582	100	2·25	4·0	10,151	220	2·97	6·4
Number of person-years of exposure.	2480·5				3415·0			

* These rates are in all cases crude rates for all ages. Therefore, although strictly comparable for each cause between humid and non-humid sheds, they should not be used for comparing the incidence of one disease with that of another, since variations in such incidences may be the result of age distribution, e.g., if the phthisis rate is low and the circulatory diseases rate is high no deduction from these rates can be made as to the relative severity of these diseases amongst weavers, an analysis of their incidence in the separate age-groups would be required. For the same reason, they cannot be compared with the cause incidence of other industries.

Diseases of the Digestive System.—For the males the claim rates are identical, the number of days of sickness is higher in the dry sheds. For single and married women both rates are higher in the dry sheds. Taken as a whole there is a suggestion of a higher incidence from this cause under non-humid conditions. The disease principally recorded in this cause group is gastritis.

Diseases of the Nervous System.—For males and single women the rates are higher in the dry sheds ; for married women the rates are very similar. No significant difference is indicated.

Diseases of the Skin and of the Urinary System.—These are small groups and reveal no significant differences.

Diseases of the Reproductive System.—This cause is unimportant except for the married women. The rates for them are somewhat higher in the dry sheds.

Other Causes.—For males the rates are very similar, being slightly higher in the dry sheds. For single women the claim rates are identical, the number of days of sickness very similar. For married women there are slightly higher rates under humid conditions. Taken as a whole no significant difference in incidence is shown.

Accidents.—A small group showing no significant differences.

Pregnancy.—More claims and more days of sickness are found in the wet sheds.

The general conclusion from this Table is that the humid environment shows no adverse influence in any cause group except that of respiratory diseases, and in this group it is only the males that are affected. On the other hand, the women in the non-humid sheds are adversely affected as regards the digestive system. With such a relatively small number of claims in each cause group it is not justifiable to conclude that these differences are significant.

A further comparison is made in Table XXXI of the number of days of sickness from each cause per claim made. This is given for the five major and more important groups, influenza, rheumatism, diseases of the respiratory system, of the circulatory system, and of the digestive system. It will be seen that for the males the only large differences occur in the circulatory and digestive groups. In the former group there were only 37 and 30 claims made under the non-humid and humid environments respectively, so that the rates are based on too small figures to be reliable. In the digestive group the number of claims made was identical under both conditions (as shown in Table XXX), but the length of claim from this cause is here found to be longer under the non-humid conditions. The significance of the difference is barely confirmed by the rates found for the female group. In both these groups each claim is of, roughly, three days' longer duration in the non-humid sheds, but this is a relatively slight difference. For respiratory diseases the duration of each claim

TABLE XXXI.—*Number of Days of Sickness (first 26 weeks) per claim* according to cause of incapacity. All Towns. Humid and Non-Humid Sheds.*

Cause Group.	Males.		Females (Single or Widowed).		Females (Married).	
	Number of Days of Sickness per Claim.		Number of Days of Sickness per Claim		Number of Days of Sickness per Claim.	
	Non-Humid.	Humid.	Non-Humid	Humid.	Non-Humid	Humid.
Influenza	24·7	25·2	28·5	24·6	29·3	26·5
Rheumatism	32·5	35·3	39·4	34·0	38·6	39·2
Respiratory System	33·2	33·4	34·7	35·9	36·2	35·9
Circulatory System	62·3	32·3	48·9	41·8	46·5	40·7
Digestive System	38·0	28·7	31·3	28·7	36·1	33·5
All Causes	34·4	29·9	34·5	31·4	39·6	36 8

* Each period of sickness was counted as a claim irrespective of whether it was linked up or not. Also for this Table *vide* footnote to Table XXX.

made by a male is the same in each group of sheds, so that the higher incidence found in the wet sheds from this cause (in Table XXX) is entirely due to somewhat more claims and not at all to claims of more protracted duration. Turning to the group of women it will be observed that the duration of claims from influenza is a little longer under the non-humid conditions. For single women the same is true of rheumatism, but for married women the length of claims shows no significant difference for this cause. The claims from diseases of the respiratory system have very similar durations in both groups of sheds for both married and single women, while the claims arising from circulatory diseases produce somewhat longer absences from work in the non-humid sheds. Judging by these durations of each claim according to cause of incapacity, again it cannot be said that the humid environment reveals itself as an adverse factor. There is no indication that it produces longer absences from employment through sickness of any particular nature than do the conditions of the non-humid sheds.

A complete analysis of sickness by cause has been made for each of the five towns chosen for investigation, but such sub-groups are too small to be of very much value. The sickness experienced is, therefore, given, in Table XXXII, only for the more important groups of causes (as in Table XXXI), influenza, rheumatism, diseases of the respiratory system, of the circulatory system, and of the digestive system.

Inspection of Table XXXII shows at once that in the individual group the number of claims made is invariably too small to allow any deductions to be made concerning the rates derived from them. The criterion must be consistency of rates for both males and females, or consistency of rates from town to town. Taking the causes each in turn the Table gives the following results :—

Influenza.—There is no consistency in the values of the rates, relative to wet and dry sheds, either from sex group to sex group or from town to town. In Preston the males have higher rates in the wet sheds, but for single women the position is the reverse, while married women show no significant difference between the humid and non-humid groups. In Burnley the males, again, suffer higher rates in the humid sheds, the single and married women have very similar rates in both groups. In Accrington the males exposed to risk are too few in number to allow any comparison. Single and married women have higher rates (more distinct in the number of claims made) in the dry sheds. Comparing Nelson, all dry, with Blackburn, all wet, the males and single women show very little difference in their rates; the married women have more claims but shorter sicknesses in the humid town.

Judging thus by towns it cannot be said that influenza shows any variation in incidence in the humid and non-humid mills.

TABLE XXXII.—*Sickness (first 26 weeks) grouped according to cause of Incapacity for Each Town investigated. Humid and Non-Humid sheds.**

Cause Group	MALES.								FEMALES (SINGLE AND WIDOWED)								FEMALES (MARRIED)							
	Non-Humid.				Humid.				Non-Humid				Humid				Non-Humid.				Humid			
	Total duration of Sickness in days.	Number of Claims made	Number of days sickness per person-year of exposure.	Number of Claims per 100 person-years of exposure	Total duration of Sickness in days	Number of Claims made	Number of days sickness per person-year of exposure	Number of Claims per 100 person-years of exposure	Total duration of Sickness in days	Number of Claims made	Number of days sickness per person-year of exposure	Number of Claims per 100 person-years of exposure	Total duration of Sickness in days	Number of Claims made	Number of days sickness per person-year of exposure	Number of Claims per 100 person-years of exposure	Total duration of Sickness in days	Number of Claims made.	Number of days sickness per person-year of exposure	Number of Claims per 100 person-years of exposure	Total duration of Sickness in days.	Number of Claims made	Number of days sickness per person-year of exposure	Number of Claims per 100 person-years of exposure
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
PRESTON.																								
I.—Influenza . .	174	5	0 64	1 84	458	14	1 59	4 85	1,344	42	1 32	4·11	1,042	47	0 67	3 01	1,071	38	1 80	6 38	1,933	66	1 77	6 05
III—Rheumatism . .	178	5	0 66	1 84	70	3	0 24	1 04	875	20	0 86	1 96	1,087	29	0 70	1 85	1,131	26	1 90	4·37	2,285	47	2 09	4 31
IV.—Respiratory .	380	6	1 40	2 21	209	6	0 72	2 08	507	13	0 50	1 27	1,540	38	0 98	2 43	989	24	1 66	4 03	1,506	42	1 38	3 85
V.—Circulatory. . . .	21	1	0 08	0 37	96	4	0 33	1 39	1,696	26	1 66	2 55	1,237	28	0 79	1 79	1,284	25	2 16	4·20	2,747	58	2 52	5 32
VI—Digestive . .	233	9	0 86	3 32	649	14	2 25	4 85	2,220	54	2 17	5 29	2,321	76	1 48	4 86	1,477	35	2 48	5 88	2,111	68	1 93	6 23
Person-years of exposure to risk			271 4				288 4				1020 9				1563 7				595 4				1091 2	
BURNLEY.																								
I—Influenza . .	933	42	0 83	3 75	1,243	55	1 12	4 94	1,985	70	1·50	5 28	1,668	65	1 49	5 79	2,131	79	1 90	7 04	2,116	78	2 14	7·91
III.—Rheumatism .	1,133	36	1 01	3 22	702	31	0 63	2 79	1,151	37	0 87	2 79	629	20	0 56	1 78	2,769	74	2 47	6 60	1,784	49	1 81	4 97
IV.—Respiratory . .	1,334	54	1 19	4 83	1,714	56	1 54	5 03	1,542	48	1 16	3 62	1,123	33	1 00	2 94	3,327	94	2 97	8 38	3,330	87	3 37	8 82
V—Circulatory.	909	17	0·81	1 52	587	16	0 53	1 44	1,489	38	1 12	2 87	908	23	0 81	2 05	3,584	81	3 20	7 22	2,519	64	2 55	6 49
VI—Digestive . .	1,823	54	1 63	4 83	1,182	43	1 06	3 86	3,089	109	2 33	8 23	1,828	76	1 63	6 77	4,076	127	3 63	11 32	4,024	115	4 08	11 66
Person-years of exposure to risk			1118 9				1113 0				1325 1				1122 9				1121 7				986 7	
ACCRINGTON.																								
I.—Influenza	20	1	0 92	4 61	122	3	1·32	3·26	504	23	1·67	7 63	1,462	56	1 52	5 83	842	35	3 78	15 70	1,909	75	3 02	11 86
III—Rheumatism . .	—	—	—	—	62	2	0 67	2 17	527	11	1 75	3 65	529	18	0 55	1 87	890	22	4 00	9 88	1,240	38	1 96	6 01
IV.—Respiratory . .	10	1	0·46	4·61	—	—	—	—	302	12	1 00	3 98	767	25	0 80	2 60	452	12	2 03	5 39	834	34	1 32	5 38
V—Circulatory. . .	—	—	—	—	21	2	0 23	2 17	212	7	0 70	2 32	1,333	30	1 39	3 12	421	8	1 89	3 59	1,019	29	1 61	4 59
VI—Digestive . .	—	—	—	—	83	5	0 90	5 43	559	17	1 85	5 64	1,417	42	1 47	4 37	1,154	22	5 18	9 88	1,599	49	2 53	7 75
Person-years of exposure to risk			21 7				92 1				301 4				961 1				222 7				632 3	
NELSON.																								
I—Influenza . .	1,441	56	1 15	4 48	—	—	—	—	1,125	39	1 32	4 59	—	—	—	—	1,281	30	2 37	5 55	—	—	—	—
III.—Rheumatism . .	965	29	0·77	2 32	—	—	—	—	879	19	1·03	2 24	—	—	—	—	659	19	1·22	3 51	—	—	—	—
IV.—Respiratory . .	866	17	0 69	1 36	—	—	—	—	808	18	0 95	2 12	—	—	—	—	553	17	1 02	3 14	—	—	—	—
V—Circulatory. .	1,376	19	1 10	1 52	—	—	—	—	1,204	23	1·42	2 71	—	—	—	—	1,085	23	2 01	4 25	—	—	—	—
VI—Digestive . . .	2,884	67	2 31	5 36	—	—	—	—	1,046	41	1 23	4 82	—	—	—	—	2,214	65	4 09	12 02	—	—	—	—
Person-years of exposure to risk			1249 0								849 8								540 7					
BLACKBURN																								
I.—Influenza	—	—	—	—	468	19	1 04	4 21	—	—	—	—	1,036	44	1 22	5 18	—	—	—	—	1,315	55	1 87	7·80
III—Rheumatism . .	—	—	—	—	756	9	1 68	2 00	—	—	—	—	581	16	0 68	1 88	—	—	—	—	1,504	40	2 13	5 68
IV—Respiratory .	—	—	—	—	579	13	1 28	2 88	—	—	—	—	1,098	30	1 29	3 53	—	—	—	—	1,328	32	1 88	4 54
V.—Circulatory. . . .	—	—	—	—	264	8	0 59	1 77	—	—	—	—	706	19	0 83	2 24	—	—	—	—	1,777	47	2 52	6 67
VI.—Digestive	—	—	—	—	756	31	1 68	6 87	—	—	—	—	1,317	46	1 55	5·42	—	—	—	—	2,385	70	3·38	9 93
Person-years of exposure to risk							451 0								849·0								704 8	

Rheumatism.—In Preston the males in the dry sheds have the higher rates; single and married women show insignificant differences only. In Burnley the males in the wet sheds have the higher rates; single and married women, again, show insignificant differences In Accrington both single and married women suffer from higher rates in the non-humid environment. Blackburn males have a longer duration of sickness than Nelson males (based only on 9 claims), while the claim rates are similar; single women are at a disadvantage in the dry town, married women in the wet town. Again, no consistent difference in incidence is revealed between the humid and non-humid sheds.

Diseases of the Respiratory System.—In Preston the males and married women have higher rates in the non-humid sheds, though in both cases the claim rates are very similar; the single women suffer more in the wet sheds. In Burnley the males have very similar claim rates, the duration of sickness being somewhat longer in the wet sheds. The single women are at a slight disadvantage in the non-humid sheds, the married women in the humid sheds. In Accrington the single women suffer more sickness from this cause in the non-humid sheds; the two groups of married women show identical claim rates but slightly longer sicknesses in the dry sheds. In all 'sex' groups the rates in Blackburn the "wet town," are higher than those in Nelson, the "dry town."

It was found in comparing all towns (*vide* p 64) that the women showed no difference in sickness rates from respiratory causes in the humid and non-humid groups, but that there was a suggestion that the males were at some disadvantage in the wet sheds. This analysis of sickness by towns shows that this difference in the male rates is derived from a slight difference in the rates found in Burnley (based upon relatively large figures), and a more considerable difference found between Blackburn and Nelson (based upon smaller figures). The difference in the Burnley rates is not sufficiently great to command confidence in its significance, especially as regards the number of claims made, while the higher rates of Blackburn, consistent for the three "sex" groups, may be due to other factors, e.g., geographical, and cannot be definitely ascribed to humidity. In other words, analysis by towns does not produce any evidence which would allow the conclusion to be drawn that respiratory diseases are more frequent amongst the population in the humid mills than amongst that in the non-humid mills.

Diseases of the Circulatory System.—In Preston the male claims are too few to allow comparison. The single women have higher rates, the married women lower rates in the dry sheds. In Burnley all three groups show higher rates in the dry sheds, but the differences are small. In Accrington the number of claims in the dry sheds is too small to allow comparison. In Nelson and Blackburn the males have similar claim rates, but a longer duration of sickness in the former town; single women are at a small

disadvantage in Nelson, and married women are similarly placed in Blackburn. In other words, no consistent difference in rates is to be seen.

Diseases of the Digestive System.—In Preston the males in the dry sheds have the lower rates, but the position is reversed for single women, while the married women show very little difference in the number of claims and somewhat longer sicknesses in the dry sheds. In Burnley the males and single women have higher rates in the dry sheds, but the married women in that environment are at an advantage. In Accrington both the groups of women have higher rates in the dry sheds. The Nelson males make fewer claims for this cause than the Blackburn males, but their duration of sickness is longer; both groups of women have higher rates in the "wet town." It will be remembered that in comparing the humid and non-humid groups in all towns together it was found that the population in the latter had higher sickness rates from digestive troubles (*vide* p. 66). The analysis thus made according to towns reveals no consistent differences in this cause group, and therefore suggests that the difference between the totals may not be a significant one.

The final conclusion arising from this review of the sickness in the humid and non-humid environments is, therefore, that no material difference exists in the two environments either in the amount or in the nature of the sickness suffered.

Summary and Conclusions.

1. It is stated that in the manufacture of cotton cloth a relatively high percentage of moisture in the air is required for good weaving. In addition, some manufacturers hold that for carrying out certain trade processes the natural moisture content of the atmosphere is not sufficient, and artificial means have been adopted for increasing the humidity. The usual practice in the weaving sheds in which large amounts of moisture are required is to inject steam or atomized water into the air. Thus, certain mills have a relatively high moisture content produced by artificial means; these are termed the *humid* or *wet* sheds. Other mills rely only on the natural humidity in the air and use no method to increase it; these are termed the *non-humid* or *dry* sheds (p. 3).

2. The trade organisations of the operatives have for many years opposed these methods of increasing the humidity in the mills, one of the grounds for their objection being a belief that the relatively hot and humid atmosphere is deleterious to health and causes a high sickness incidence in the humid sheds. Their protests have led to certain regulations for the humid sheds, one of which is the prohibition of artificial humidification at certain wet and dry bulb temperatures (p. 4). The operatives

are still dissatisfied with the conditions and require the total abolition of all artificial humidification. Such a step, in the opinion of the employers, would seriously impair production of certain types of cloth.

3. The investigation here described was designed to test the operatives' contention that artificial humidification is responsible for excessive rates of sickness in the humid as compared with the non-humid sheds. A sample of mills of each type was chosen and the sickness experience of all the weavers within these mills was obtained for the year 1st August, 1925 to 31st July, 1926. This sickness was related to the environment in which the weaver was at work during the year. The mills chosen were situated in five Lancashire towns, Preston, Burnley, Accrington, Nelson, and Blackburn. In the first three towns sheds of both types, humid and non-humid, are to be found; in Nelson only non-humid sheds and in Blackburn only humid sheds are existent. The sickness of, in all, some twenty thousand weavers was investigated. The details required concerning the work-places of the weavers were obtained from the mills themselves; the sickness history was obtained from the National Health Insurance Approved Societies of which the weavers were members (pp. 5–13 and Table I).

4. A year's investigation of the sickness incidence found in all the humid sheds and that found in all the non-humid sheds reveals no significant difference between the two, either in number of days of sickness experienced (Tables II and III), in number of claims made (Tables II and III), or in number of persons suffering from one or more sicknesses (Table V) during the year of investigation. The only difference is a slight excess of sickness in the non-humid sheds, and the number of days of sickness lost per claimant is longer in the non-humid sheds (Table IV) than in the humid. This slight excess of sickness in the non-humid sheds is, however, due to the presence of a few more very long claims in this group (Table VI) and as these very long claims form only a small percentage of the *total* claims no material meaning can be attached to the slight differences thus found (pp 13–24).

5. Analysis of the sickness, town by town, produces a similar result, i.e., the humid sheds are not found to possess a higher sickness incidence than the non-humid sheds (pp. 24–39, Tables VII to XVII).

6. It is argued that in times of unemployment sickness claims tend to increase. During the year of inquiry the non-humid mills investigated were closed on the average for a longer period of time than were the humid mills. Lest this should have increased the sickness found in the non-humid mills as compared with the humid mills and thus vitiate the conclusion just given, comparison was made between two groups of mills, humid and non-humid, forming only a part of the total, which experienced (according to the measure adopted) only slight unemployment

during the year in question. The sickness rates for these sub-groups were found to be nearly identical with those already found for the totals which suggests that unemployment was not a factor of importance in producing the sickness rates found to prevail (pp. 40–46, Tables XVIII to XXI). In addition the stability of the rates makes it improbable that the results are due to the fluctuations of sampling.

7. The classification of mills as humid and non-humid makes no allowance for the variations within these groups. To take this into account, wet and dry bulb temperature readings were obtained from each mill over a period of five months in the year of investigation. The mills were then classified according to these readings, and the sickness experience related to their dry bulb, wet bulb, relative humidity, physiological saturation deficit, and combinations of these variables. Although the groups thus obtained were often too small to give reliable results when taken alone, the rates were sufficiently consistent to make it justifiable to state that no significant difference in the sickness incidence was present within the range of variation found to exist. In addition no difference was found between the extremes in the humid group and the extremes in the non-humid group, i.e., between the "very dry" and the "very wet" (pp. 46–63, Tables XXII to XXIX, Figs. 1 and 2).

8. Analysis, involving rather small figures, according to the *nature* of the incapacity suffered in the two environments yielded no evidence of any consistent or distinct differences in the distribution of specific sicknesses as between the humid and non-humid sheds (pp. 63–71, Tables XXX to XXXII)

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PREFACE.

In a previous Report published by the Board* reference has been made to certain industrial processes, in which the detail to be discriminated is so fine that, however high the illumination provided may be, the eye must be kept quite near to the object, with the result that some degree of continuous strain is imposed on the muscles of convergence and accommodation†. The results of the investigation embodied in that Report clearly suggest that benefit will be derived from the use of spectacles specially prescribed to relieve excessive convergence and accommodation, thereby virtually restoring the eye to its normal condition. It was found, for example, that the three operatives studied, who were engaged in linking (a process in hosiery manufacture), all responded to the treatment in showing a distinct increase in output and other evidence of lessened eye fatigue, whilst the assistance given by the spectacles was so greatly appreciated, that their use has continued ever since.

The investigation was admittedly preliminary in character, and no minute refinements in fitting the spectacles were adopted. In view of the encouraging results obtained, the Board, on the recommendation of the Committee on Physiology of Vision, decided to extend the investigation to certain other occupations involving the discrimination of fine detail, namely, the mounting of filaments by hand and "drawing-in" in weaving. The results of this further work fully confirm those of the earlier inquiry, in showing that the use of the spectacles has in every instance been associated with an increase in output ranging from 1 to 26 per cent. and averaging about 12 per cent., whilst the general tenor of the workers' opinion, as given in Appendix II, has in every instance been favourable.

It has been pointed out, however, that since the operatives selected were not originally homogeneous as regards visual acuity, some doubt must remain as to how far the resulting improvement is attributable to the correction of ordinary visual defects rather than to the special arrangements made for relieving eye-strain Investigation, accordingly, is now being undertaken in order to determine this point, and an experiment planned in which the relative improvements of persons with normal (emmetropic) vision will be compared with those of persons with visual defects (such as myopia and hypermetropia), after both have been fitted with the special glasses.

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* Weston, H. C. and Adams, S. (1927). The Effect of Eyestrain on the Output of Linkers in the Hosiery Industry.—I.F.R.B Rep. No. 40.

† When a near object is viewed, two muscular actions take place simultaneously, the one causing a slight rotation of the eyes inwards towards each other, thus allowing the image to fall on the same point of the retina in each eye, the other a change in the curvature of the lenses of the eyes, the object being thereby kept in focus. The former of these is known as *convergence*, the latter as *accommodation*.

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Meanwhile, in the opinion of the Board, the combined results of the two investigations suggest that the use of spectacles of the kind described in the report afford a simple, but effective, means of eliminating, or at least relieving, the eye-strain that is now often associated with continuous fine work, while the cost involved (amounting to about 15*s*. for each pair of glasses) will be much more than offset by the higher efficiency of the worker. It is, however, perhaps desirable to point out, first that in order to secure the best results, and indeed to avoid actually harmful effects, the spectacles must be carefully prescribed for each individual, so as to correct any visual defects that may already be present in addition to relieving eyestrain, and secondly, that (as will be seen by comparing the particulars on pp. 8 and 16) the appropriate lens and prism corrections to be inserted for the latter purpose must vary according to the distance maintained between the eye and the object.

April, 1928.

THE RELIEF OF EYESTRAIN AMONG PERSONS PERFORMING VERY FINE WORK.

By H. C. Weston, M.J. Inst. E., and S. Adams, M.Sc.
Investigators to the Board.

CONTENTS

PART I.—A CONSIDERATION OF "EYESTRAIN" AND ITS RELIEF, WITH CONCLUSIONS DRAWN FROM TWO INVESTIGATIONS.

INTRODUCTION.

Constant progress in the development of improved physical aids to manufacture is tending to increase the amount of "fine" work done in factories, while, at the same time, the practice of modern ideas as to the division and subdivision of labour has the effect of increasing the number of workers who, for the full factory day, are engaged solely on fine work. The conditions imposed upon the eyes by work of this kind, and the effect of these conditions on the comfort and efficiency of the worker, are therefore matters which deserve consideration.

The attention devoted in recent years to factory lighting is evidence of a growing recognition of the necessity for, and of the value of, improving conditions which affect visual perception, and definite evidence of the extent of the loss of production which may result from poor illumination is now available.

The provision of ample illumination, however, will not necessarily prevent the experience of eyestrain by persons engaged in doing very fine work, for the character of the latter may be such that its details can be clearly seen only when the eyes are brought very close to it, that is, when they are fully accommodated and convergent. Such a condition involves extreme muscular effort, or "strain," which cannot be long sustained or repeated with great frequency, without considerable discomfort.

The effort required to see objects which are clearly visible only when the eyes are fully or almost fully accommodated may be compared with that of lifting a weight which can only just be raised when the maximum effort of the group of muscles concerned is used. If this maximum effort has to be exerted frequently, the onset of fatigue is very rapid, and the frequency and duration of the idle periods essential for recovery will reduce the total work done in a given time, as compared with that which would be possible by the use of a smaller but more continuous effort.

This is also true of the eyes. If maximum accommodation has to be used, it will be found necessary to rest the eyes frequently by looking at more distant objects, and so changing the amount of accommodation. If, however, the degree of accommodation necessary to see the work is reduced by an addition to the refracting power of the eyes, the frequency and duration of the changes of accommodation necessary in order to avoid over-fatigue will be reduced, and the visual attention given to the work facilitated.

Involuntary " rests," varying in length and frequency according to the nature of the work, are taken by all workers and serve, of course, to limit fatigue to a more or less tolerable degree. It is certain that eye fatigue is limited in this way. Complaints of severe eyestrain due to the work are not as common as they would be if no such defensive measure as this were adopted and, for this reason, the absence of complaints does not imply that a particular type of work is not a potential source of strain. Not infrequently, it is only when such strain as the worker has permitted himself to experience has been reduced or eliminated, and he has had an opportunity of reflecting upon present and past experience, that he realises the extent of the strain to which he was previously habituated. If, however, we find that the adoption of suitable glasses for certain types of work results in a substantial increase of production, it must be inferred that, if the visual effort required to achieve this rate of production could be made without glasses, considerable eyestrain would be inevitable.

The Use of Glasses.

The use of glasses then, not only to correct defects of vision—which are more common than is generally realised and increase the risk of eyestrain,—but for the purpose of reducing the accommodation and convergence of the normal eye required by very fine work, is a measure which naturally suggests itself. The primary object of using glasses is, of course, merely to enable fine work to be done without eyestrain but, it follows from what has been said on the subject of " rests," that their use may enable an *increased* amount of work to be done with less strain than was experienced without them. Such an increase might be expected to follow immediately the introduction of glasses which afford immediate assistance to the eyes. Several factors, however, may tend to delay any such objective evidence of the value of an innovation which is at once beneficial to the individual.

In the case of an experienced worker, the average rate of working is the result of well established habits, and of a manual skill developed to an extent permitting a rate of production with which the other capacities involved, such as those of vision, can keep pace. Such habits are not easily disturbed and, in the case of very delicate work, it may well be that the rate of production cannot respond to improved conditions of vision until a further degree of manual skill has been developed. With the learner, not only has manual skill to be acquired, but a form of visual skill, or specialisation, appears to be developed, and is of no little importance in relation to production. For example, the trained eye of the weaver sees a broken thread in his warp much more rapidly than the untrained eye of the casual observer, who may, however, possess greater visual acuity. While the adoption of glasses will facilitate the development by the learner of this visual skill, the introduction, during the learning period, of a new factor may temporarily disturb

progress ; but, in any case, as with the experienced worker, development of manual skill must take place before the benefit of glasses becomes fully apparent. Ultimately manual dexterity will set a final limit to the rate of production, so that it does not follow, when no increase of output is observed, that no relief to the eyes has been afforded by glasses.

It may be stated as a general rule that the use of glasses should be tried whenever the details of adequately illuminated work cannot be clearly seen unless the eyes are brought within a distance of ten inches from it. In such cases, the principle adopted in the experiments described in the succeeding sections of this report has been to provide glasses of such power that the amount of accommodation required is no more than would be used if the eyes were removed to a distance of about 15 inches from the work. Thus, in the case of a person, say thirty years of age, if work has to be done with the eyes about six inches away, practically the maximum accommodation available—assuming the eyes are emmetropic—has to be used, and four dioptre lenses will be required to reduce accommodation to the standard amount suggested above

In the two investigations described later, after correction of individual errors of refraction, a total addition of four dioptres was provided for the very fine work of filament sorting and mounting, and two dioptres for "drawing-in," a process which is described in Part II*b*. With these glasses were combined prisms of six and two degrees respectively, in order to assist convergence.

The reactions of any individual to a change made in the conditions associated with the work may be greatly influenced by the mental attitude which the change provokes, so that, when experiments are made with only a few subjects, special care is necessary to avoid undesirable effects which may vitiate any merit of the change.

The introduction of a new method of work, or a new machine, is perhaps less likely to give rise to any difficulties of this kind than the introduction of glasses, for the latter affect the personal appearance of the wearer and, especially in the case of women, may sometimes excite resentment. If this happens, estimation—by such an indirect method as the study of output—of the relief afforded to the eyes is almost certain to yield a negative result. Care was taken, therefore, to explain the object of the experiments which have been made, and to consider, as far as possible, the aesthetic sense of the subjects in such a matter as the choice of rims, and no real difficulty was experienced in securing the willing co-operation of the workers. After wearing the glasses provided for a few days, all the subjects considered they were deriving some benefit from them, and were quite prepared to give them a fair trial. At the end of the experimental period—ten weeks in the case of the investigation described in Part II*a*, and seven weeks for that reported in Part II*b*—all the

subjects were unwilling to discard their glasses and resume work without them. Six months later the glasses were found to be still in regular use, so that there is no doubt the subjects were satisfied that they enabled the work to be done with greater comfort.

Summary of Conclusions.

Objectively, very definite evidence of the value of the glasses is provided by the output data presented in the succeeding sections of this report, and the conclusions drawn from these data will be summarised here.

In the first place, the relief and assistance afforded to the workers by the glasses enables their rate of output to be substantially increased. The amount of this increase varies, in individual cases, from about 8 to 26 per cent. for drawing in, and from less than one per cent., in an exceptional case, to nearly 20 per cent for filament sorting and mounting These figures refer only to experienced workers and there is evidence that a still greater increase may be expected in the case of a learner.

The increases recorded, excluding that of the learner, suggest that the use of glasses, prescribed according to the principle laid down herein, by persons doing work comparable to that described, may effect an average increase of output of the order of 12 per cent. This conclusion is in close agreement with that reached as the result of a previous study of the effect of glasses used for linking *

It is recognised that the number of cases so far studied is too small to justify any broad generalisation, and also that the effect observed is, to some extent, due to the correction of defects of vision. It seems fair, however, on the evidence available, to accept the figure given as a tentative evaluation of a method for increasing the comfort and efficiency of persons doing fine work, the full possibilities of which remain to be explored.

Objective evidence of the benefit of glasses may be delayed for some time after their introduction, for reasons which have already been discussed, but the data obtained suggest that the higher rate of output ultimately established may be maintained with great consistency from hour to hour and from day to day.

The effect of providing the learner with glasses is more marked than is the case with experienced workers, and it is suggested that the use of glasses from the commencement of the learning period would not only increase the initial output of the beginner, but would increase the slope of the learning curve and shorten the period required to attain proficiency.

* The Effect of Eyestrain on the Output of Linkers in the Hosiery Industry, by H. C Weston, M.J Inst E , and S. Adams, M.Sc. Industrial Fatigue Research Board, Report No 40 H M.S.O. 1927. Price 1*s*. 0*d*. net.

The loss of efficiency of those engaged on fine work, due to accommodative asthenopia, or to the defensive " rests " taken to avoid or limit this form of eyestrain, is exaggerated, as would be expected, by errors of refraction and inferior visual acuity. It is, therefore, obviously desirable, in the interests of worker and employer alike, that the sight of candidates for fine work should be tested and any defects properly corrected.

PART II.—TWO EXPERIMENTS WITH REDUCED ACCOMMODATION FOR "CLOSE" WORK.

(*a*) **Mounting Lamp Filaments.**

Description of the Work.

The subjects used for the first experiment described in this report were engaged in performing two operations in connection with the manufacture of telephone switchboard indicator lamps. The first of these operations, performed by two girls, was that of separating individual carbon filaments, which are made in bundles, and are received by the girls in a tangled condition. Each filament consists of a single loop, about three millimetres in diameter, and of two parallel straight portions which the girls cut to a length of about half an inch before separating the filaments. The diameter of about 80 per cent. of the filaments used was 0·04 or 0·05 mm., the remainder ranging from 0·025 to 0·07 mm. (about one to three thousandths of an inch); the fineness of the work will thus be readily understood.

The filaments are very fragile and the manipulations necessary to disentangle them are performed with the aid of a pair of tweezers, constant visual attention being necessary. The separated filaments are placed on special trays and taken to the girls engaged in mounting them on the supporting wires fused in the glass "bead" of the lamp.

Each girl has a circular table about 18 inches in diameter, mounted on the bench in such a manner that it can be rotated by hand. The table is provided with a concentric band, about 4 inches wide, of opal glass, thus affording a contrasting background for the filaments, which are laid on it. Around the inner edge of this band are arranged a number of miniature clips of the familiar "Bulldog" pattern. The girls commence their cycle of operations by placing in each of these clips a glass "bead" with its filament-supporting wires. This operation, as in the case of the succeeding ones, is done with the aid of tweezers and requires care and attention, though, compared with the handling of the filaments, it is an operation which can be performed quickly and without extreme accommodation and convergence of the eyes.

The next operation consists in taking filaments from the tray and placing them on the white band of the mounting table, one opposite each "bead" with the ends of the filament directed towards the centre of the table. This operation is more delicate than the preceding one, and requires much closer vision The filaments are now ready for the actual operation of mounting. This is done by picking up the filament with the tweezers and placing its ends against the supporting wires in the "bead" and painting them with a special graphite cement The delicacy of this operation and the concentrated visual attention which it demands will be appreciated if it is realised that the diameter of

the filament is only about half that of a human hair. Finally, the beads, with the filaments mounted on them, are removed from the clips and replaced on the tray.

ILLUMINATION.

Each of the mounting tables is provided with a local light mounted 15 inches above it, 60-watt gas-filled lamps are used, which supply an illumination at the work place of about 35 foot/candles The illumination of the work probably never falls much below this value, as the lamps are frequently used even in summer when good daylight is available.

METHOD OF INVESTIGATION.

The two girls engaged in sorting filaments and three of the girls engaged in mounting filaments were used as subjects. Their output was measured hourly for a period of six weeks before glasses were worn. During this period their sight was tested by Dr. Duke Elder and suitable glasses prescribed. The work was done with the eyes only about six or seven inches from it, and the glasses provided effected a reduction of accommodation of four dioptres. 6-degree prisms were combined with the lenses to reduce the convergence required. Only one of the subjects had normal eyes, the others having some degree of astigmatism, which was corrected by the glasses supplied. Particulars of these glasses are given in the following table:—

Particulars of Glasses.

Subject.	Age.	Process	Particulars of Glasses. Sph	Cyl	Prism Base in R. and L.
A	—	Filament Sorting	R.+3·5 L.+3·5	+ ·5 + ·5	6°
B	25	Filament Sorting	R +4 L.+4	— —	6°
C	32	Filament Mounting	R +3 L.+2·25	+ ·5 + ·75	6°
D	20	Filament Mounting	R.+3 L.+3	+1 +1	6°
E	23	Filament Mounting	R.+3·5 L.+3·5	+ ·5 + ·5	6°

Since the glasses restricted clear vision to a comparatively short distance, only the lower half of the lenses were used, so that distant vision could be obtained by looking over the top of them. The necessity for removing the glasses during working hours in order to look across or walk about the room was thus avoided.

The output of the workers was measured hourly for a period of ten weeks while the glasses were worn, and comparison of the figures obtained with those for the control period shows, in every case, an increase of output, though this is slight in the case of those who were previously the best workers When the glasses had been in use for several days all the subjects expressed their complete satisfaction with them, and declared that they would not like to do the work again without them.

Discussion of Data.

The average rate of output of each subject, with and without the glasses, is given in Table I, (see Appendix I) together with the individual increase of output. The table shows that the subjects studied differ considerably in their individual capacities for production, and, to facilitate comparison in this respect, the individual rank in relation to the best worker is given These figures are of interest as showing the extent to which individual differences of output of fine work may depend upon visual capacities, and may be reduced by means which enable the eyes to be used under more comfortable conditions

It has been said that, with one exception, the subjects of the experiment were astigmatic, and it is therefore not easy to estimate how much of the effect observed when the glasses were worn is due to the relief afforded to the muscles concerned with

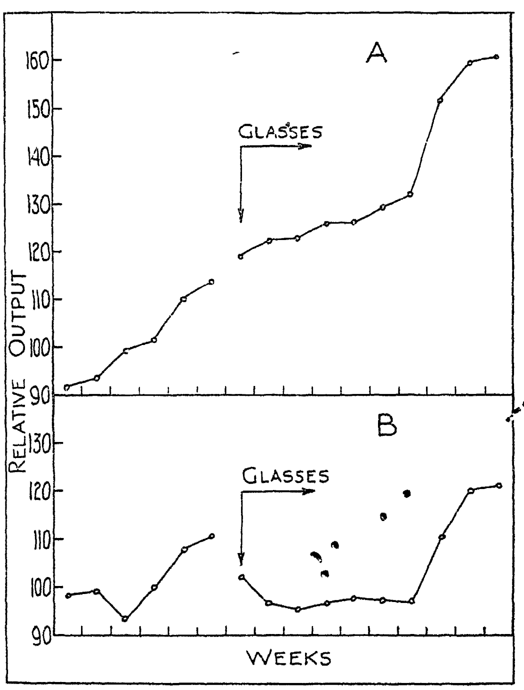

Fig. 1.—Weekly Variations of Hourly Output Rate. (Filament Sorters)

accommodation and convergence, and how much is the outcome of the improvement of vision which would naturally follow the correction of astigmatism. This difficulty does not arise in the case of subject B, who was not astigmatic, and whose average rate of output improved by 3 per cent. when the glasses were worn.

The variation of output of subjects A and B from week to week during the control period, and the period when glasses were worn, is given in Table II, from which Fig. 1 is plotted. The curve relating to A, who had only six months' experience, shows a steady rise during the control period, as the result of practice After the introduction of glasses the effect of practice is still seen, but the very marked increase of output in the last three weeks of the experimental period appears to be a result of the use of glasses. Similarly, in the case of B, a marked improvement occurred at the same time, and the data suggest that a considerable period may sometimes elapse before the beneficial effect of glasses becomes apparent.

In Table III the variation of output throughout the day of all the subjects is given, and from these figures the curves shown in Figs. 2 and 3 have been plotted.

So far as A is concerned, her increased experience partly accounts for the much higher level of the output curve when the glasses were worn. In the case of B, however, only a small increase of output is shown, but the shape of the curve obtained when the glasses were worn is typical of the curve often given by those engaged on monotonous work and suggests that work was not done to full capacity. Probably the rate of output of this subject during the last three weeks of the test period gives a truer indication of the benefit derived from the glasses. Further investigation of the weekly average output records kept by the firm has confirmed this view, the average output of B during a period of six months after hourly records were discontinued being nearly 20 per cent. higher than that attained without the glasses. These results show then that a period of two months, or even longer, may in certain cases elapse before the relief of eyestrain is adequately expressed in terms of production.

Referring to the curves showing the variation of output of the three girls engaged in mounting filaments (Fig 3), it is obvious that, in addition to the actual increase of output when the glasses were worn, the shape of the work curve has, in each case, been improved. The curve relating to subject D very closely approaches a straight line when glasses are worn, while all the curves show little evidence of fatigue towards the end of the day, thus confirming the evidence of the workers themselves, who stated that their eyes were not tired after the day's work when the glasses were used.

The small increase of output observed in the case of E is not surprising. During the control period, this worker was easily the most efficient of the group and was given the most difficult work throughout the investigation. She appears to have acquired the

greatest possible skill in handling her very delicate work, and it is unlikely that any improvement of conditions, other than a change of the actual method of work, would react upon her rate of output. It does not follow, however, that because the glasses had no appreciable effect upon output in this case, they were of no benefit to the worker, who, in fact, would not now work without them.

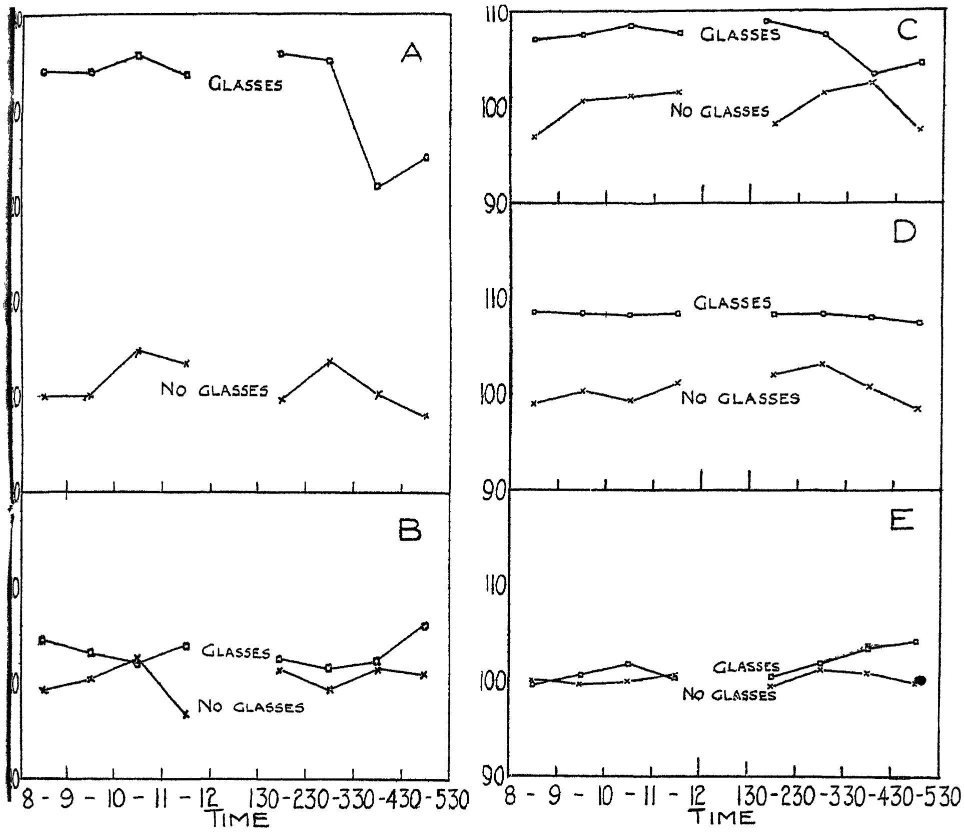

FIG. 2.—Filament Sorters FIG. 3.—Filament Mounters
Variations in Hourly Output Rate Throughout the Day.

The improvement of output of C and D during the glasses period was more gradual than that of A and B, and no abrupt, but deferred, increase occurred as in the case of the latter. During the six months immediately following the period when hourly output records were taken, the efficiency of D showed a further increase of 4·3 per cent., making a total increase with the glasses of 11·7 per cent., though that of subject C remained at the level recorded ten weeks after the glasses were adopted. The efficiency of E fell about 7 per cent. during the six months just referred to, but this was due to her employment on work of special difficulty. Subject A left the factory after the termination of the experimental period, so that her subsequent history is unknown.

The variation of output throughout the week of each subject is shown in Figs. 4 and 5, which have been plotted from data given in Table IV. The curve relating to B before the glasses were worn suggests that, with the experienced worker, an unusual loss of practice occurs as a result of the week-end break. This feature is removed when glasses are used, so that it may be inferred that the shape of the weekly characteristic curve was previously determined, not so much by any daily improvement in manual dexterity, as by a gradual readaptation to the visual requirements of the work. The characteristics of the curves relating to C, D and E during the pre-glasses period are not very unusual. In each case, however, the curve falls on Tuesday, and this may be due, directly or indirectly, to excessive strain experienced during Monday, when an effort was obviously made to achieve an average rate of output before adaptation to the work had taken place. At all events, this effect practically disappears when glasses are brought into use, and the output curve of each subject is smoothed out—a feature which is very noticeable apart from the elevation of the general level of the curves. As regards subject D, the curve obtained when glasses were worn, like that shown in Fig. 3 for the typical day, becomes practically a straight line, variability of output having been reduced to a remarkable extent.

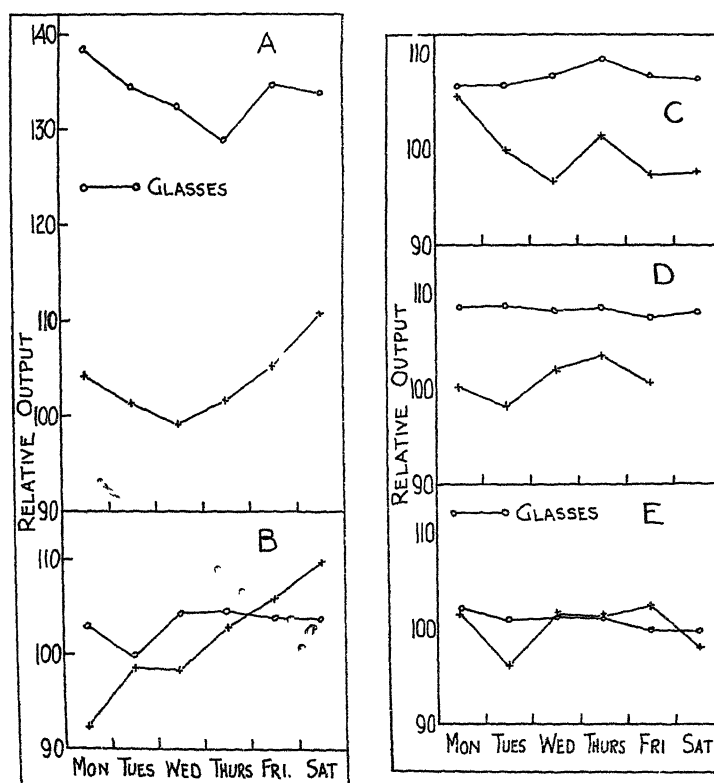

FIG. 4.—Filament Sorters. FIG. 5.—Filament Mounters.
Variations in Hourly Output Rate throughout the Week.

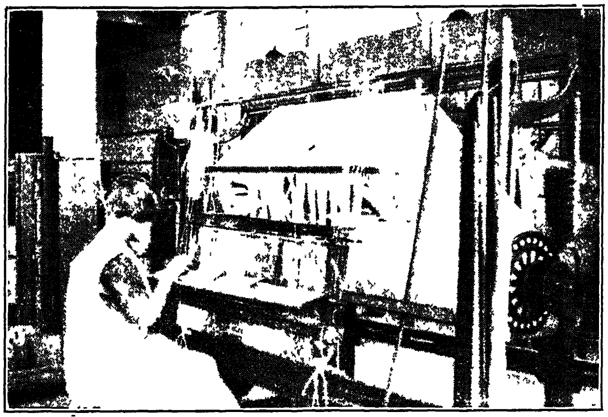

Plate I.

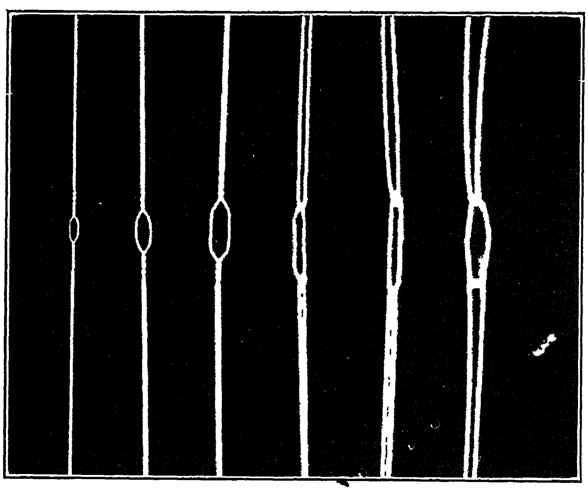

Plate II.

PLATE III.

(*b*) Drawing-in (Looming).

DESCRIPTION OF THE WORK.

Before the weaver's beam, containing the warp threads, is ready for the loom each thread or " end " has to be drawn through one of the eyes of a series of healds, used to form the pattern of the cloth, and also through one of the spaces or " dents " of a reed. This process is usually done by hand, with the aid of a hook and reed-knife, on a frame as shown in Plate I. The fineness of the work depends upon the " count," or thickness, of the yarn, the size of the heald eyes, and the closeness of the reed, which, in turn, depends upon the number of threads to the inch which the cloth is to have In addition to the fineness of the yarn its colour also affects the facility with which it can be seen. With the majority of the warps drawn-in during this experiment the threads, or ends, had to be drawn through 123 heald eyes per inch, and as four sets of healds were used, one behind the other, the selection of the correct eye required close vision. In Plate II the actual size of some typical heald eyes is shown, those on the left are made of wire and those on the right of cotton. Both types were used during this investigation, the middle one of each group being the size generally employed. Drawing-in with wire healds is more difficult than with cotton healds and, for this reason, a separate record was kept of the rate of output with each type of heald. Plate III shows the working position of the drawer, who uses her right hand to manipulate the hook with which the thread is drawn through the heald eye, and her left hand to operate the reed knife. The time taken to draw-in a warp, and therefore the time spent in doing close work, varies from about $3\frac{1}{2}$ hours to 6 hours or more, after which 15 or 20 minutes is spent in removing the warp and setting up a new one.

ILLUMINATION.

The experiment was carried out in a large well-lighted room on the ground floor of a two-storey building. The daylight factor, found by photometric measurements taken outside and immediately below the windows, and inside where the drawer inserts her hook in the healds, was 11·8 per cent.

Artificial light was provided by means of local lights mounted on universally jointed brackets, which can be seen on the left in Plate I. Gas-filled opal lamps rated at 60 watts were used in aluminium hooded reflectors. The operatives adjusted these lamps so as to throw the light on the eyes of the healds, and the average illumination found at this point was about 31 foot/candles. The type of reflector used prevented the experience of glare by the operatives.

Method of Investigation.

It was only practicable to measure the output of the drawers twice daily, at the end of the morning and afternoon spells, and careful records were kept throughout the investigation of any variable factors, such as the type of heald used, the closeness of the reed, colour of warp, etc., so as to ensure that the effect of the glasses could be estimated by comparative output data obtained during periods when similar working conditions prevailed.

Six experienced operatives were studied during a control period of seven weeks, and during a further period of similar duration after they had been examined by Mr. T. G. Clegg, F.R.C.S., and supplied with glasses prescribed by him. Particulars of these glasses are given in the accompanying table.

Particulars of Glasses.

Subject.	Age.	Spherical.		Cylindrical.		Prism Base in R. & L.
		R.	L.	R.	L.	
A ..	30	+2	—	—	+4	2°
B ..	27	+2·5	−1	−3·25	−2·5	2°
C ..	30	+1·25	+2·75	−0·75	+1·0	2°
D ..	52	−2	−2	−1·5	−1·5	2°
E ..	26	−2·5	−3	−0·5	—	2°
F ..	18	+0·5	+0·25	−0·75	−0·5	2°

Discussion of Data

In Table V the relative output of each operative during the morning and afternoon of the average day of the control and experimental periods is given. The average output of all the operatives is also shown, and from these data Fig. 6 has been plotted. In the morning an average increase of output of 18 per cent. occurs when the glasses are worn and a still greater increase is noticeable in the afternoon. During the latter spell, the individual rate of improvement is more variable, but consideration of the figures given for the individual operatives clearly shows that the effect of the glasses is to reduce the tendency for the rate of output to fall towards the latter part of the day.

The data given in Table VI, and the curves plotted from them in Fig. 7, show that there is a similar tendency for the high rate of output to be maintained during the latter part of the week when glasses are used. Here again the effect varies considerably with different individuals, hence the averages given are subject to a higher mean variation than the corresponding figures relating to the control period. There is no doubt, however, that the increases of output observed were not accompanied by any increase of fatigue.

In Table VII the average actual output of each subject during the control and experimental periods is given, together with the individual percentage increase of output which occurred when the glasses were worn.

The extent of the individual improvement is interesting when considered with reference to the ages of the subjects and the condition of their eyes, as disclosed by Mr Clegg's examinations. (See the table of prescriptions, and also Appendix III.)

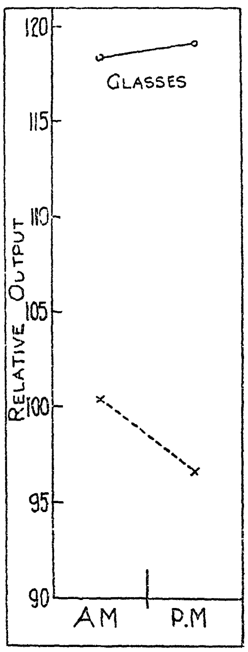

Fig. 6.—Variation of Output Diurnal

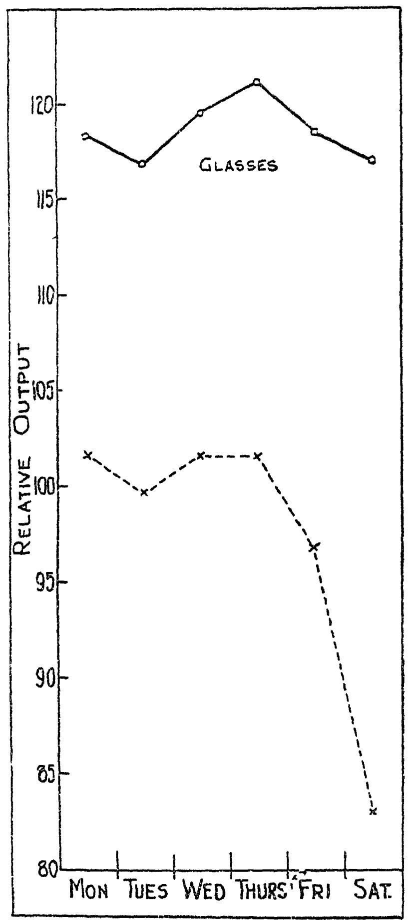

Fig. 7.—Daily Variation of Output throughout the Week

Subject A is not likely to have been greatly inconvenienced by the astigmatism of her left eye, and the effect of the glasses, in her case, probably represents fairly well the magnitude of the improvement which may be expected of persons of average age and normal vision if they are provided with glasses suitable for this work. Subject B had a considerable degree of error in both eyes, the correction of which would be expected to lead to

greater improvement than would occur in the case of a normal person. C's error was small and her improvement with the glasses unusually high. The remaining three operatives were all myopic, while D was also presbyopic and her relatively small increase of output is not surprising in view of her age. Subject E had considerable myopia, and had been wearing glasses of too low a power, hence her excellent improvement when provided with more suitable glasses. The improvement in the case of F is comparatively small, but this is partly explained by the fact that, during the experimental period, she had a new and inexperienced "reacher."* She had, however, only a moderate degree of myopia and had, therefore, to use, during the control period, very little more accommodation than that required of A, for instance, when aided by glasses.

The data so far discussed refer only to work done with cotton healds. The greater difficulty of the work when wire healds are used is due to the colour of the latter and the fact that their eyes are usually smaller than those of cotton healds. (See Plate II.) Only a comparatively few periods were worked by each subject with wire healds, so that the average output rates given in Table VIII are probably less reliable than those relating to cotton healds. However, while the magnitude of the increases of output recorded may be open to some doubt, they suggest that, as would be expected, the use of glasses is even more advantageous for work with wire than with cotton healds. The single decrease of output shown is of doubtful significance since it occurred with the oldest operative who worked only four periods with wire healds when wearing the glasses.

All the subjects have continued to wear the glasses since the completion of the experimental period, and are satisfied that they afford relief to the eyes and enable the work to be done with greater comfort and facility than was previously the case.

* The "reacher" sits at the back of the healds and selects the warp threads for the drawer. An experienced reacher does not retard the speed at which the drawer can work

APPENDIX I.

TABLES.

TABLE I.—*Average Output with and without Glasses. (Filament Sorters and Mounters.)*

Subject.	Age.	Process.	Actual Hourly Output without Glasses	Rank in Relation to Best Worker.	Actual Hourly Output with Glasses.	Rank in Relation to Best Worker.	Per Cent. Increase of Output with Glasses.
				%		%	
A ..	—	Filament Sorting.	301·3	51·3	415·5	66·6	33·9
B ..	25	Filament Sorting.	605·0	100·0	623·6	100·0	3·0
C ..	32	Filament Mounting.	93·2	64·7	100·1	69·1	7·4
D ..	20	Filament Mounting.	115·5	80·2	122·1	84·3	5·7
E ..	23	Filament Mounting.	144·0	100·0	144·9	100·0	0·6

TABLE II.—*Weekly Variation of Hourly Output Rate of Filament Sorters.*

Weeks.		Relative Hourly Output. A	Relative Hourly Output. B
1	No glasses	91·89	98·33
2	No glasses	93·48	99·15
3	No glasses	99·33	93·37
4 .. .	No glasses	101·33	99·80
5	No glasses	110·10	107·84
6	No glasses	113·71	110·46
1	Glasses worn	119·01	102·23
2	Glasses worn	122·26	96·53
3	Glasses worn	122·46	95·29
4	Glasses worn	126·00	96·44
5	Glasses worn	125·97	97·96
6	Glasses worn	129·26	97·55
7	Glasses worn	131·90	96·97
8	Glasses worn	151·82	110·22
9	Glasses worn	159·87	120·41
10	Glasses worn	160·87	121·33

TABLE III.—*Variations in Hourly Output Rate throughout the Day.* (*Filament Sorters and Mounters.*)

Subject.	A		B		C		D		E	
Time.	Relative Hourly Output.*									
	N.G.	G	N.G.	G.	N.G.	G	N G.	G.	N G.	G.
8–9	99·90	134·06	99.15	104·31	96·88	107·18	98·96	108·57	100·00	99·76
9–10	99·93	133·87	100·36	103·12	100·42	107·54	100·26	108·40	99·62	100·51
10–11	104·73	135·74	102·52	102·06	101·07	108·51	99·30	108·22	99·92	101·88
11–12	103·26	133·48	96·77	103·91	101·39	107·77	101·03	108·40	100·55	100·41
1.30–2.30 ..	99·51	135·83	101·22	102·46	98·28	108·95	101·99	108·31	99·23	100·23
2.30–3.30 ..	103·64	135·09	99·15	101·57	101·50	107·62	103·11	108·57	101·11	101·71
3.30–4.30 ..	100·00	121·88	101·43	102·24	102·46	103 32	100·86	108·05	100·90	103·33
4.30–5.30 ..	97·88	125·10	100·99	106·09	97·63	104·66	98·44	107·44	99·79	104·04

* Calculated on the basis that the average hourly output rate of each subject during the whole control period = 100 per cent. This method simplifies comparison of individual improvement when wearing glasses.

N.G. = No glasses.

G. = Glasses worn.

TABLE IV.—*Daily Variation of Output.* (*Filament Sorters and Mounters.*)

Subject.	A		B		C		D		E	
Day.	Relative Hourly Output.									
	N.G.	G.	N.G.	G.	N.G.	G.	N.G.	G	N G.	G
Mon.	104·03	138·41	92·52	103·00	105·49	106·42	100·00	108·48	101·60	102·08
Tues.	101·26	134·51	98·52	99·73	99·80	106·48	98·09	108·65	96·11	100·90
Wed.	99·06	132·38	98·17	104·13	96·66	107·50	101·90	108·13	101·46	101·09
Thurs.	101·62	128·84	102·86	104·51	101·40	109·38	103·37	108·48	101·18	101·04
Fri	105·09	134·83	105·81	103·93	97·32	107·61	100·43	107·44	102·15	99·87
Sat.	110·77	133·87	109·62	103·90	97·74	107·45	—	108·13	98·05	99·78

TABLE V.—*Diurnal Variation of Output without and with Glasses. (Loomers.)*

Subject.	Relative Output.			
	No Glasses.		Glasses.	
	a m.	p.m.	a.m.	p m.
A	99·0	99·4	114·9	119·5
B	105·6	89·2	130·4	128·0
C	99·9	97·1	122·2	125·1
D	94·8	102·1	110·7	106·2
E	96·7	99·5	119·1	128·9
F	106·6	92·5	113·2	107·0
Average	100·4	96·6	118·4	119·1
Mean Variation ..	±11·25	±10·6	±10·2	±14·1

TABLE VI —*Daily Variation of Output (average of all subjects) without and with Glasses. (Loomers.)*

Day.	No Glasses.		Glasses.	
	Relative Output.	M V	Relative Output	M V.
Monday	101·6	±8·8	118·3	± 6·3
Tuesday	99·7	±7·6	116·8	± 7·7
Wednesday	101·6	±5·3	119·5	±10·7
Thursday	101·6	±5·9	121·1	±12·0
Friday	96·8	±8·0	118·5	±12·8
Saturday	83·0	±7·4	117·0	±14·1

TABLE VII.—*Average Number of Ends drawn-in per Hour for each Experimental Period. (Loomers.)*

Subject.	No Glasses.	Glasses.	Percentage Increase due to Glasses.
A	829	955	+15·19
B	850	1,074	+26·35
C	661	814	+23·14
D	668	723	+ 8·23
E	778	964	+23·91
F	769	835	+ 8·58

TABLE VIII.—*Average Number of Ends drawn-in per Hour for Each Experimental Period. Wire healds used. (Loomers.)*

Subject.	Number of Periods.		Average Number of Ends drawn-in per Hour.		Percentage Increase or Decrease.
	No Glasses.	Glasses	No Glasses.	Glasses.	
A	16	14	517	716	+38·49
B	9	9	575	802	+39·48
C	7	11	488	573	+17·42
D	11	4	522	457	−12·45
E	13	13	497	654	+31·59
F	9	5	465	576	+23·87

APPENDIX II.

COMMENTS OF EXPERIMENTAL SUBJECTS. (LOOMERS.)

Subject A.—This subject commenced wearing the special glasses on 9th March, and continued wearing them for three weeks. This preliminary experiment was carried out in order to find out whether she was able to wear them with comfort She showed an increase in output and a marked decrease in fatigue, though the comments given below are not wholly satisfactory There is no doubt that this was partly due to the fact that this operative had never worn glasses before, and did not think that she was flattered by her appearance in them. Horn rims would undoubtedly have solved the difficulty. (The glasses supplied were fitted with steel frames.)

On the first day of this preliminary experiment the subject wore the glasses all day. She said she had a slight headache at the end of the day, but this quickly wore off. Later remarks were: "I can't see so well this morning," "rather blurred," "I find them rather heavy," "I have a touch of headache when I put them on, but this soon wears off," "I can't see my work any better in them," "the eyes of the healds seem smaller when I have the glasses on."

All subjects, with the exception of D, commenced wearing the special glasses on 28th March. Subject D was away from work owing to illness, and commenced wearing them on 9th May The following comments were collected at various times during the experiment:—

Subject A.—Age 30. Experience, 6 years. This subject appeared to be more comfortable in the glasses when the other subjects commenced wearing them There is no doubt that the initial strangeness of wearing glasses had worn off

Subject B.—Age 27. Experience, 12 years. The only comment made by this subject on the first day was: "I shall get used to them." On the second day she said: "the work looks much clearer." She also remarked: "they are very good at a certain distance from the work." One day during the first week she was heard to remark to herself "these glasses are a damn nuisance, I can't see nowt but work" After the first week she said: "I wouldn't like to be without them now."

Subject C.—Age 30. Experience, 15 years. This subject appeared very restless on the first day so the glasses were taken to the optician for slight adjustment. On the third day she said: "They're champion; I can see my work clearer and they're a great help." "My eyes have been aching each night for some time, but they didn't ache last night." "The glasses are so much better to work with when we have two shades of the same colour."

Subject D.—Age 52. At the end of the first week this subject said: "I should be lost without them for they make the work much clearer." "As the day goes on I feel the advantage of them." She remarked to the overlooker: "These glasses have been a boon to us."

Subject E.—Age 26. Experience, 10 years. This subject wore the glasses with comfort from the first day. She remarked: "They're champion." "They're a lot better than my own." "The work looks bigger." During the second week one of the lenses was accidentally broken, and the subject had to give them up whilst they were being repaired. She said, "I'm lost without them; I can't draw so well and the work seems smaller and makes me fumble."

Subject F.—Age 18. Experience, 3 years. On the first day this subject remarked: "They're champion, and the work is a lot clearer." "They're good in every way." "I can count the reed easily now, and there is no blurring of the dents as before when the glasses were not worn."

At the end of the experiment each subject was invited to say what she thought of the glasses. The following are the verbatim remarks:—

Subject A.—"They're champion when the weather is bright. They appear blurred when it is dull. I feel I have to stare when looking at the back shaft. My left eye is much more comfortable with the glasses on. I am going to take them to the optician's because of the blurring when the light is poor and I shall wear them permanently"

Subject B.—"I shall continue to wear them, in fact, I wouldn't like to be without them. My eyes are all right at night now—they have never been the same before My eyes used to feel tired at the end of the day, but they don't now. I can get more work off with them. I can go to the pictures in comfort. My eyes feel champion altogether."

Subject C.—"I can't do as well without them. I can read now without strain. I feel I'm doing something I shouldn't if I don't wear them I used to have an awful pain across my eyes before I used the glasses, but I don't get it now I shall wear them always at work. I feel strange if I don't put them on. I seem to have got on better since I had them."

Subject D.—"I can see my work better than before. I shall always wear them at work. There's nothing to improve them at work. The work seems much clearer."

Subject E.—"I like them very much. My eyes have been much better since I commenced to wear them, and I shall stick to them. My eyes used to smart at night, but they have not done so since I have worn them. They make work a lot easier and I shouldn't like to be without them. I had never done a poplin in a morning until I had the glasses."

Subject F.—"They're all right, and a lot better for work. I shall keep wearing them as long as I can. My eyes were terrible when I went home before I wore the glasses, but I've not been bothered since. I think I'm getting through more work since I started with the glasses."

APPENDIX III.

NOTE BY T. G. CLEGG, F R C S

The method employed was careful subjective testing and in each case a +2D spherical was added to the distance correction and a 2° prism, base in to each lens, making a total prismatic assistance of 4° to the convergence. It was found that a higher degree of convex spherical assistance and stronger prisms were not accepted for the range of work, which varies between 18 and 20 cms. from the face.

Subject A.—The right refraction was normal, but the left had a moderate degree of mixed astigmatism, and in each with the correction the visual acuity was practically normal. She had not previously worn glasses.

Subject B.—Had already had glasses which she did not wear, but she took − 3·25 D cyl. in one eye and − 2·5 D cyl. in the other With these and the proper sphericals she only had a visual acuity of 6/12, but this acuity no doubt will become raised after wearing correcting lenses for some time.

Subject C.—She had quite a low degree of error of a minus character in the right, and a plus character in the left

Subject D.—She is myopic and presbyopic but had not previously worn any cylindrical correction, which in her case amounted to − 1·5 D.

Subject F.—Had never worn glasses, but was found to have moderate myopia with a low degree of astigmatism.

All the above had healthy eyes.

Subject E.—Was already wearing minus sphericals of too low a power. Her visual acuity with the correcting lens was fully normal although she has extremely numerous fine pigment deposits on the posterior surface of each cornea These showed as a fine brownish cloud with the ordinary methods, but with the slit lamp and eye microscope they were very evident as discrete pigment particles. In other respects the eyes were healthy.

Although some of the above would probably be more efficient with the accurate correction of their refraction, in my opinion the increased efficiency is for the most part due to the addition of the +2 D sph. and the 2° prism base in to the distance correction.

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